

FINAL

Remedial Process Optimization Handbook

Prepared For



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EXECUTIVE SUMMARY

During the next decade, the Department of Defense (DoD) will spend over one billion dollars per year on the operation, maintenance, and monitoring of environmental remediation systems. In addition to exercising good stewardship of taxpayer dollars, the DoD will be responsible for ensuring that each remediation system is effectively making progress toward site cleanup objectives and remains protective of human health and the environment. The purpose of this handbook is to assist remediation site managers and their operating contractors in addressing these significant responsibilities. The handbook has been organized to support site managers with two levels of remedial process evaluation: annual (or Phase I) evaluations which focus on the collection of key performance and cost data and minor system optimizations, and Phase II remedial process optimization (RPO) evaluations which address the more significant issues of overall system effectiveness, together with consideration of alternative regulatory approaches and new technologies.

This handbook describes the general regulatory and technical framework for

evaluating existing remediation systems, regardless of the type or complexity of the remedy. Emphasis is given to the reevaluation of cleanup goals and how potentially unachievable goals can be updated based on new regulatory approaches. Technical discussions focus on key concepts for evaluating remedial system effectiveness and efficiency. Appendices and technical references are provided to assist the user with many of the technology-specific details of the RPO evaluation. Due to their frequent use on DoD sites, the emphasis of this guidance is on pump-and-treat and soil vapor extraction systems.

RPO is not a “stand alone” process. It must be closely integrated with existing regulatory requirements such as 5-year Record of Decision (ROD) reviews, RCRA permit reapplications, and operating properly and successfully (OPS) demonstrations at sites which are scheduled for transfer to non-DoD entities. This handbook describes the remedial process evaluation requirements mandated by these regulations, and how the RPO evaluation sequence can be used to directly support these requirements.

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ACRONYMS AND ABBREVIATIONS

ACL	alternate concentration limit
AFBCA	Air Force Base Conversion Agency
AFCEE	Air Force Center for Environmental Excellence
ARAR	applicable or relevant and appropriate requirements
ASTM	American Society of Testing Materials
BRAC	base realignment and closure
BTEX	benzene, toluene, ethylbenzene and xylene
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CERFA	Community Environmental Response Facilitation Act
CFR	Code of Federal Regulations
CSM	conceptual site model
CSSRA	chemical and site-specific risk assessment
DNAPL	dense nonaqueous-phase liquid
DoD	Department of Defense
DQO	data quality objective
ERPIMS	Environmental Restoration Program Information Management System
EPA	Environmental Protection Agency
FOST	finding of suitability to transfer
FR	Federal Register
kg	kilogram
LNAPL	light nonaqueous-phase liquid
LTM	long-term monitoring
MAJCOM	Major Command
MCL	maximum contaminant level
mg	milligram
NAPL	non-aqueous-phase liquid
NCP	National Contingency Plan
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollution Discharge Elimination System
OM&M	operation maintenance and monitoring
OPS	operating property and successfully
OSWER	Office of Solid Waste and Emergency Response
PBMS	performance based measurement system
PC	personal computer
PFD	process flow diagram
POTW	publicly owned treatment works

ppb	part per billion
ppmv	part-per-million-by-volume
QA	quality assurance
RAB	restoration advisory board
RBCA	risk-based corrective action
RBSL	risk-based screening level
RCRA	Resource Conservation and Recovery Act
PTT	Performance Tracking Tool
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RPO	remedial process optimization
RSO	remedial system optimization
SSL	soil screening level
SSTL	site-specific target level
SVE	soil vapor extraction
TCE	trichloroethylene
TI	technical impracticability
TIO	Technology Innovation Office
TPH	total petroleum hydrocarbon
USEPA	U.S. Environmental Protection Agency
UST	underground storage tank
VMP	vapor monitoring point
VOC	volatile organic compound

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SECTION 1 – INTRODUCTION

1.1 OVERVIEW

Remedial process optimization (RPO) can be defined as a systematic approach for evaluating and improving site remediation processes so that maximum risk reduction is achieved for each dollar spent. Although RPO is frequently associated with the optimization of remediation systems and *how* the cleanup will be completed, it is equally important to review *why* certain cleanup goals have been established and to update those decisions based on new regulatory options. Just as the technical approach to remediation should be upgraded to take advantage of scientific advances, changes in regulatory framework, such as risk-based cleanup goals and the growing acceptance of monitored natural attenuation, should be considered in the optimization process. An effective RPO program will pursue a wide range of optimization opportunities.

1.2 PURPOSE AND APPLICATION OF THIS HANDBOOK

The purpose of this document is to provide environmental managers with practical guidance on how to evaluate and optimize existing remediation systems. This guidance is in agreement with, and supports the Air Force Center

for Environmental Excellence (AFCEE) strategy to improve conceptual site models (CSMs) and to establish and regularly evaluate Data Quality Objectives (DQOs) for active remediation sites.

It is anticipated that two levels of RPO evaluation will be necessary; these will be referred to as Phase I and Phase II RPOs. Phases I and II are differentiated by the level of detail in the evaluation and effort expended. A third phase of the RPO involves the implementation of recommendations.

This handbook has been organized into 4 sections which provide general guidance on a variety of RPO topics including:

- This introduction to RPO concepts;
- How to complete a Phase I evaluation and when to expand the effort to Phase II (Section 2);
- How to complete a more detailed Phase II evaluation (Section 3); and,
- Implementation of RPO recommendations (Section 4).

In addition to providing general guidance, this document provides valuable cross-references to more specific RPO topics that are now available on the AFCEE webpage or other electronic libraries. This handbook was prepared in consultation with Environmental Protection Agency (EPA) officials, the Defense Logistics Agency, and other Department of Defense (DOD) agencies that are also developing guidance on remediation optimization. A listing of the key documents that were referenced while preparing this handbook is provided as Appendix A.

When Is An RPO Evaluation Required?

RPO should be viewed as an ongoing responsibility of the DoD and its contractors who are hired to operate, maintain, and monitor remediation systems. At least once each year, the operating contractor should complete a Phase I evaluation to review key performance data and evaluate the progress toward site cleanup goals, while ensuring remedy protectiveness. Section 2 provides guidance on the information that should be collected and the analysis that should be performed during these annual reviews.

Several situations will warrant a more rigorous Phase II RPO evaluation:

- Preparation for mandatory regulatory reviews such as 5-year ROD reviews or RCRA permit reapplications;
- Preparation of an operating properly and successfully (OPS) demonstration document at sites that are scheduled for transfer from government control;
- Any remediation system that is clearly failing to achieve its designed cleanup objectives based on the annual Phase I RPO evaluation;
- Sites with an opportunity to pursue new cleanup goals based on changes in regulatory policy and/or new understanding of site conditions or chemical toxicity.

Responsible DoD environmental managers should prioritize sites for Phase II RPO evaluations based on regulatory requirements and the potential cost benefits. For pump-and-treat (P&T) systems, Phase II RPO evaluations are most useful after the initial 2 to 3 years of system operation since the effectiveness of most P&T systems can be evaluated after this period. A Phase II RPO evaluation is always needed for systems that are obviously failing to meet their design objectives, regardless of the age of the system.

RPO can be used to evaluate a wide range of remediation systems and regulatory frameworks. The greatest opportunities for optimization and cost avoidance exist at large pump-and-treat systems. However, a streamlined version of RPO can be applied to other remediation systems. Although this handbook is primarily intended for the optimization of existing remediation systems, optimization principles can also complement the remedial design process and promote more effective and efficient future systems.

1.3 EXPECTED BENEFITS OF RPO

Multiple benefits are expected from the RPO program. RPO is expected to ensure that existing remediation systems remain protective of human health and the environment, to facilitate the reevaluation of cleanup goals, track and report on remedial progress, reduce operating and monitoring costs and ultimately accelerate site closures and property transfers.

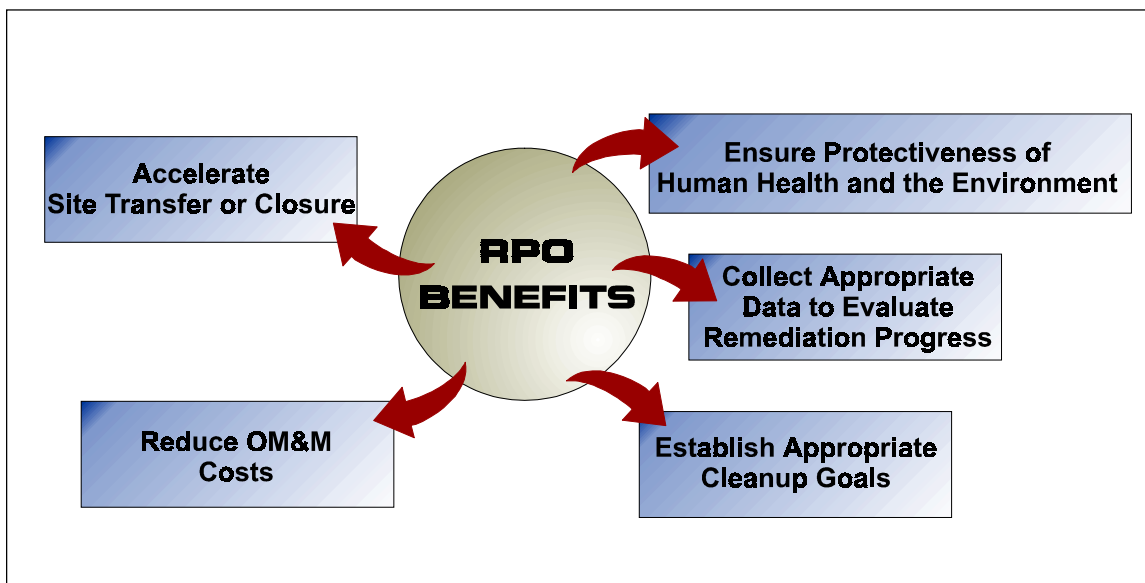
1.3.1 Ensure Protectiveness

Phase I and Phase II RPO evaluations will review site monitoring data to ensure that contaminants of concern are not migrating to potential receptors and that remedial systems are not creating new pathways for receptor exposure.

Groundwater, soil gas, and ambient air data will be reviewed to evaluate the protectiveness of the in-place remedies. Factors such as current land use, enforcement of institutional controls, and any changes to potential exposure scenarios need to be updated during the RPO evaluation.

1.3.2 Reevaluation of Cleanup Goals

RPO evaluations provide an opportunity to review site cleanup goals. Recent regulatory changes encourage the use of more flexible, site-specific cleanup goals. Less stringent cleanup goals are currently applied at sites where engineering and institutional controls can be used to effectively separate receptors from contaminated soil or groundwater. The emergence of the USEPA's "Brownfields" program and the *American Society of Testing Materials (ASTM) standard guide on risk-based corrective action (RBCA)* have added flexibility to cleanup goals, particularly for sites in non-residential areas. For sites where existing cleanup goals appear to be unattainable, the RPO process will help organize information for other regulatory options such as technical impracticability (TI) waivers. Since many site remedies are based on chemical toxicity assumptions and exposure assumptions that were determined over 5 years ago,



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Figure 1.1 Benefits of RPO

reevaluation of these assumptions and resulting remediation objectives is an important benefit of the RPO process.

1.3.3 Tracking and Reporting of Remedial Progress

RPO evaluations provide an opportunity to examine the effectiveness of an existing remedial system in relation to established cleanup goals. A clear definition of the type and quality of data that is required to track remediation progress should be established as the DQOs for individual remediation systems. This is particularly important for pump-and-treat systems, which are very expensive to operate and often inefficient at removing contaminants from an aquifer. The RPO evaluation will track the expected

performance versus actual performance of a remediation system, and can be used to update fate and transport model predictions so that a realistic cleanup time-frame can be estimated. Based on this evaluation, the existing system can be optimized or replaced with a more effective technical approach.

The RPO evaluation provides feedback on system effectiveness that should foster increased interaction and communication with the regulatory officials. Increased communication will also lead to a greater appreciation of the goals and constraints of the regulatory agency. The RPO evaluation provides regulatory officials with updated site information and demonstrates the DoD's continuing

commitment to protect human health and the environment in a deliberate and cost-effective manner.

Note: RPO evaluations are intended to be internal studies to assist the DoD in managing site remediation projects. Phase II studies should be completed in coordination with regulatory agencies, however, RPO activities are not subject to regulatory approval except where specified by law. Implementation of RPO recommendations may require regulatory approval, therefore, regulatory participation is strongly encouraged.

1.3.4 Reduced Operating and Monitoring Costs

Completing a comprehensive Phase II RPO evaluation will require experienced hydrogeologists, chemists, environmental engineers, scientists, risk assessors, and regulatory specialists. Fortunately, the cost of RPO evaluations is generally offset by savings in the future operation and maintenance (O&M) of the target remedial system. Based on AFCEE's initial Phase II RPO pilot program at over 10 sites, O&M cost savings in excess of 25 percent have been identified at most sites.

In addition to optimizing remediation systems, the RPO process will evaluate the long-term monitoring plan and analytical protocol in place at each site. Be-

cause groundwater, soil, and system monitoring can be significant cost items in the annual O&M budget, the RPO evaluation will carefully review each monitoring well and data point to validate its usefulness in tracking system performance. The DQOs established for each site should focus on the collection of necessary and relevant information to chart the progress of site remediation. Unnecessary monitoring wells will be recommended for abandonment and the frequency of monitoring will be reviewed to eliminate meaningless repetition. The analytical protocols for each site will be reviewed to ensure that only contaminant data that are needed for documenting system effectiveness are included, and that expensive "over analysis" is eliminated. DQOs for analytical data will be evaluated to ensure that quality assurance (QA) requirements are appropriate for the intended use of the data.

1.3.5 Accelerated Site Transfer or Closure

The ultimate benefit of RPO is achieving site cleanup goals more rapidly and efficiently. This is particularly important at federal facilities that have been deactivated and are awaiting property transfer based on OPS demonstrations. The EPA and DoD understand that optimized remediation systems will

not only save billions of taxpayer dollars over the coming decades, they will provide a less polluted and encumbered environment for future generations. At sites where cleanup is impossible with current technologies, prudent and cost-effective steps should be taken to isolate and contain contaminants using a combination of engineering and institutional controls to protect human populations and the environment.

1.4 OVERVIEW OF REMEDIAL PROCESS OPTIMIZATION

Figure 1.2 illustrates the basic RPO evaluation sequence. The RPO evaluation can be divided into three phases as described below:

1.4.1 Phase I - Annual Review of System Performance

A major objective of the RPO program is to focus the attention of DoD environmental managers and their operating contractors toward site cleanup objectives and the performance of existing remedial systems. At least once each year, site monitoring data and treatment system performance should be evaluated to determine if the remediation system is making progress toward cleanup goals. Section 2.1 describes methods of organizing site data for this purpose. These data collection activities and an annual performance review are critical compo-

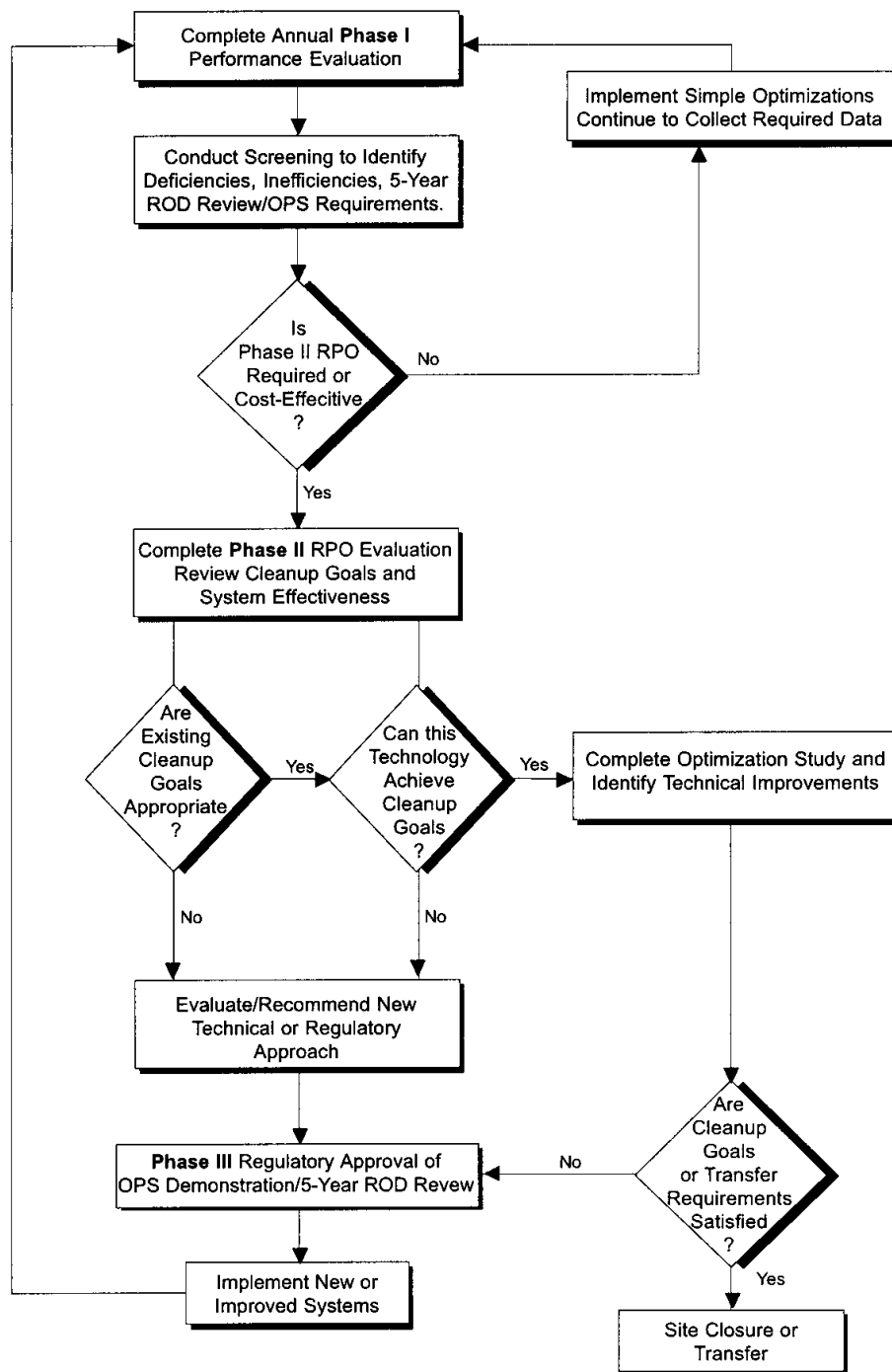
nents of RPO and must be a priority of environmental managers. Based on the results of the annual evaluation, each site should be screened to determine if a more intensive Phase II evaluation is warranted. In many cases, simple optimization improvements can be completed by the operating contractor as action items from the annual performance evaluation.

Before proceeding into a Phase II RPO evaluation, each site should be screened to determine if the costs associated with Phase II are likely to be recovered through future O&M cost avoidance. This decision must be based on site-specific factors such as the general effectiveness of the system, the cost of the optimization study, the current O&M costs for the remedial system, and the number of years that it is expected to operate. Generally, the longer the system is expected to operate, the greater the potential for payback.

1.4.2 Phase II - Intensive RPO Evaluation

A Phase II evaluation will generally require the formation of an independent RPO evaluation team to more completely study and identify specific optimization opportunities. To minimize conflicts of interest, it is recommended that the Phase II RPO team be directed

**FIGURE 1.2
REMEDIAL PROCESS OPTIMIZATION SEQUENCE**



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by an independent team chief who has no contractual relationship to the remedial system operations contractor. On sites with formal Records of Decisions (RODs), or RCRA corrective action programs, Phase II RPO evaluations should begin 18 months prior to mandatory program reviews (5-year ROD reviews, 10-year permit reapplications). For remediation systems located on federal facilities scheduled for closure, RPO will be useful for reducing long-term operations and monitoring costs and for gathering the data which will be required to demonstrate that a system is operating properly and successfully.

Two parallel activities are envisioned: evaluation of site cleanup goals and risk reduction objectives; and, evaluation of the effectiveness and efficiency of the current remediation and monitoring systems. Phase II will include a thorough review of the cleanup goals that have been established for a site, the regulatory history behind those goals, and the opportunities that may exist for revising cleanup goals without sacrificing the overall protectiveness of the remedy. Emphasis should be placed on the use of engineering and institutional controls to protect site workers in industrial/commercial settings so that more realistic, risk-based cleanup goals can be established. For BRAC facilities, this

will require careful negotiation of leases or land sales to ensure that land use controls provide continued protection of human health and the environment.

The Phase II evaluation will also determine if the performance of the existing remedial system can be expected to achieve cleanup goals. In addition to evaluating the effectiveness of the existing remediation system, opportunities for remedial systems optimization (RSO) and new approaches such as monitored natural attenuation should be considered. Once the best combination of existing and new technical approaches has been selected, the optimized or new system must be evaluated in terms of its ability to cost effectively achieve cleanup goals within a reasonable timeframe.

Forming a Phase II RPO Evaluation Team

A successful RPO evaluation will involve participation by several contributing team members. The following individuals are recommended for a Phase II RPO evaluation team:

- A DoD project leader or site manager;
- Experienced engineers, chemists, risk assessors, and geologists familiar with existing and emerging

site remediation technologies and monitoring approaches;

- An engineer and/or scientist who participated in the design, construction, or operation; and,
- A key technical person from the lead regulatory agency if a significant change to regulatory or technical approach is anticipated.

This group should develop a work plan to clearly establish the goals and expectations of the RPO evaluation. A sample Statement of Work has been provided in Appendix B to assist the DoD project manager in obtaining qualified consultants for Phase II RPO evaluations.

1.4.3 Phase III - Implementation of RPO Recommendations

The activities of the final phase of optimization will depend upon the results of the first two phases. For example, if an optimized pump-and-treat system is expected to achieve numerical cleanup goals for dissolved contaminants in a reasonable timeframe, the DoD may commit to an extended O&M period,

establish intermediate performance goals, and continue to optimize the remediation system and monitoring program until cleanup goals are achieved. This decision will require minimal regulatory involvement because it does not propose significant changes to the approved remedy.

However, if site monitoring data indicates that source removal is technically infeasible, the DoD may choose to pursue an isolation or plume containment strategy. In this case, the “optimum” remediation system is one that will accomplish long-term isolation/containment at minimum cost. An additional goal may be to reduce the area of the site that must remain under land or groundwater use restrictions. Continuing RPO for isolation/containment remedies will include periodic evaluations of emerging technologies and new regulatory options. Significant regulatory coordination and approval will be required to change primary remedial objectives. Section 4 provides additional guidance on the regulatory procedures available for implementing more complex RPO recommendations.

SECTION 2 – ANNUAL PHASE I EVALUATIONS

Section 1 described the general RPO program. The Phase I RPO consists of annual data collection activities, a basic performance evaluation, and identification of system optimization opportunities. The Phase I evaluation will generally be completed by the supporting O&M contractor under the oversight of the responsible DoD environmental site manager. An example SOW for Phase I contract services is included in Appendix B. The following subsections describe the general requirements of the Phase I RPO evaluation program.

2.1 PHASE I DATA COLLECTION AND ANALYSIS ACTIVITIES

Throughout the year, the responsible DoD site manager and O&M contractor(s) for the site should assemble site data for a Phase I performance evaluation. Considerable time and money are expended in the collection of soil and groundwater data for monitoring remediation systems. These data must be easily stored and accessed if it is to be useful for RPO evaluations and a variety of regulatory reporting requirements (e.g., five-year ROD reviews and OPS demonstrations). While the Environmental Restoration Program Information Management System (ERPIMS) database

was created for the management of large volumes of site investigation and long-term monitoring data, a simple personal computer (PC)-Excel™-based data collection system can be developed for tracking remediation system performance and costs. Appendix F provides additional details on an example PC-based Performance Tracking Tool (PTT) that has been created to assist site managers and their consultants in meeting RPO record-keeping and reporting requirements.

Using a PTT, the site manager or operating contractor will input key remediation performance and cost information for each remediation system operating at the facility. Rather than requiring all analytical results, this database will only ask for a few "indicator" contaminants that have been selected to track remediation effectiveness. Historical monitoring data from each extraction well and key monitoring points will be entered so that the software can create simple trend-analysis charts. Appendix F includes examples of the data tables and charts that should be created during annual Phase I RPO evaluations. At a minimum, the following data tables and

graphics should be collected and prepared :

- A table summarizing the concentrations of an indicator contaminant of concern at individual groundwater monitoring wells, soil gas vapor monitoring points, and extraction wells. An indicator contaminant is generally the chemical that is expected to be the most difficult to clean up to its remediation goal. The table will provide historical concentrations at each monitoring point and will be used to track changes in the concentration of contaminants over the lifetime of the system. Only contaminants that exceed cleanup goals should be listed, and the table should include the target cleanup goals for each contaminant.
- A graph that depicts the changes in concentration over time of an indicator contaminant(s) at several key monitoring well locations, including the source area.
- A graph showing the total mass of contaminants removed to date for the entire system and from each extraction well. This can be compared to initial estimates of contaminants in the subsurface; and,

- An updated site map showing the capture radius for groundwater or soil gas extraction wells;
- A summary table of the extraction/injection flow rates at individual wells and the total flow treated, and contaminant mass removed.
- A summary of influent and effluent data from all aboveground treatment systems, including total mass of contaminants destroyed and/or discharged. The summary should also compare effluent values to regulated discharge limits;
- An itemized accounting of annual O&M costs. Cost data should be entered into a PTT cost template (see Appendix F). These data will be available for the site manager's review and for determining future requirements and cost-saving opportunities.

2.2 PHASE I PERFORMANCE EVALUATION AND COST INVENTORY

2.2.1 System Performance Evaluation

At least once each year this data should be reviewed by a qualified engineer or scientist to determine if the remediation system is making progress toward design performance objectives and the ultimate cleanup goals for the

site. Phase I performance evaluations should focus on the general effectiveness of the existing system based on available monitoring data. The tables and graphic displays described in Section 2.1 should be adequate for most Phase I evaluations. Section 3 of this handbook describes more detailed methods of evaluating system effectiveness and efficiency. This information should be reviewed by the Phase I contractor and used to guide the general Phase I evaluation. Due to the level of effort required for many of the analysis methods described in Section 3, these methods are normally reserved for Phase II RPO evaluations. This section describes the following minimum “performance checks” which are recommended for all remediation systems.

Phase I Performance Checks

- Are the performance criteria and ultimate cleanup goals for the remediation system clearly defined and understood by the site manager and operating contractor?
- Are contaminant concentrations continuing to decline at all monitoring points and extraction wells?
- Has the rate of contaminant mass removal increased, decreased, or remained the same over the past 6-12 months?

- Is the effluent from aboveground treatment systems in compliance with regulated discharge standards?
- Is the existing remedy containing contaminants of concern and are exposure pathways controlled to ensure protectiveness of human health and the environment?
- Is the existing remedial system operating in compliance with the regulatory decision document?

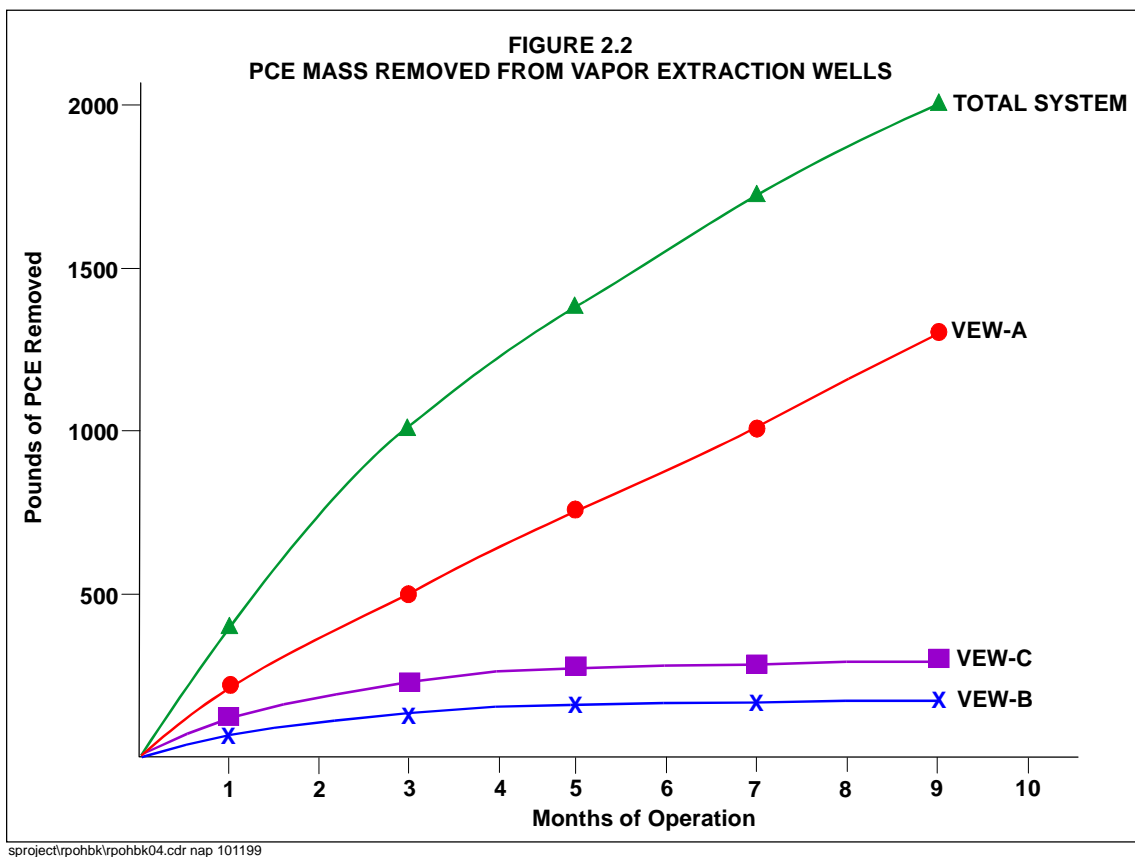
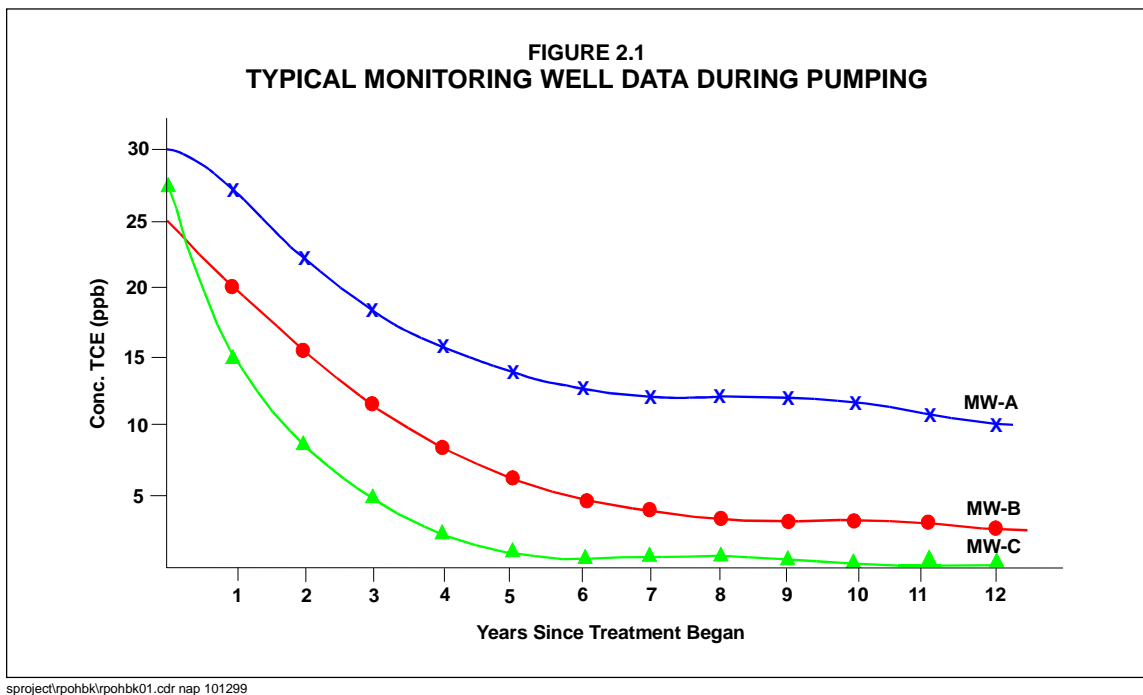
Understand Performance Criteria/Cleanup Goals - Performance criteria can be viewed as milestones on the road to achieving final site remediation goals and site closure. These milestones must be measurable and should relate to data that are routinely collected at the site. In some cases, these intermediate goals may have been established during the system design or are included in regulatory decision documents. Because system performance can not be assessed without an understanding of these goals, all Phase I evaluations should begin with a written statement of the performance criteria for the remediation system(s) and ultimate cleanup goal(s) for the site. An example performance criteria might be to “reduce average TCE groundwater concentrations by 50 percent during the first two years of operation and prevent downgradient migration.”

Evaluate the Rate of Decline in Contaminant Concentrations - One indication of remediation progress is a continuing decline in contaminant concentrations at all wells or vapor monitoring points. Figure 2.1 illustrates the typical pattern of contaminant concentration decline in most groundwater pumping systems. At this site, TCE concentrations steadily declined during the first 6 years of pumping and then leveled off as TCE removal became limited by its desorption from aquifer soils. During years 6 through 12, the rate of contaminant removal has significantly decreased, while the cost per pound of TCE removed has significantly increased. This site is a candidate for a more detailed Phase II evaluation.

Evaluate the Rate of Mass Removal – At many sites, contaminant concentrations alone do not provide an accurate assessment of remediation progress. Concentration data is influenced by the dilution effects of clean water or soil gas entering the site. The mass of contaminants being removed by groundwater and soil gas extraction systems provides an important indication of remediation progress. Figure 2.2 illustrates the mass removed over time from a system of soil vapor extraction wells. Vapor extraction well (VEW-A) continues to remove PCE

from the soil surrounding this well. In contrast, VEW-B and VEW-C are now removing little additional mass during each month of operation. To maximize mass removal, the Phase I RPO evaluation could recommend reduction or elimination of soil gas extraction from VEW-B and VEW-C and an increased extraction rate from VEW-A, or installation of an additional VEW in the vicinity of VEW-A.

Evaluation of Effluent Discharges - Effluent discharges from most extraction systems are subject to treatment requirements which are specified in a discharge permit or written into the regulatory decision document. These can include contaminant concentration and hydraulic limits on sanitary sewer or surface water discharges, and limits on the mass of contaminant discharged to ambient air. For sites utilizing reinjection to groundwater, concentration limits (often drinking water standards) are enforced. The effectiveness of above-ground treatment systems in achieving discharge standards should be documented during the Phase I RPO evaluation. A copy of discharge compliance reports provided to regulatory agencies should be included in the Phase I RPO file maintained by the operating contractor or DoD site manager.



Protectiveness Evaluation - The ability of the existing remediation system to protect human health, ecological receptors and the surrounding environment should be evaluated. The Phase I RPO evaluation should document that:

- the remediation approach is adequately containing contamination to prevent migration toward potential human or ecological receptors;
- appropriate land and groundwater use restrictions are being enforced to prevent undesirable risks due to uncontrolled exposure to contaminants; and,
- remediation workers are adequately protected and are operating in accordance with established health and safety procedures.

Overall Compliance Evaluation - The operating contractor and DoD site manager should review the regulatory decision document(s) and current discharge requirements to ensure that the current system is in compliance with regulatory requirements.

2.2.2 Cost Inventory

Accurate cost accounting is a critical component of RPO. While some O&M contractors are required to keep accurate expense records, many are not required to keep these records under "fixed-price" contracts. Without an accounting of how

costs are incurred in the operation, maintenance, and monitoring of remedial systems, it is difficult to predict the cost impact of system changes and to project future cost savings due to optimization or technology replacement. *The EPA Guide to Documenting and Managing Cost and Performance Information for Remediation Projects* provides useful examples of cost accounting for a variety of remediation systems. A detailed cost spreadsheet should be created to assist site managers and operating contractors with cost accounting responsibilities. Table 2.1 illustrates a typical cost accounting spreadsheet for a pump-and-treat system. The cost spreadsheet should be completed once each year by the operating contractor and submitted to the site manager for review and approval. This annual cost accounting is a mandatory element of the Phase I RPO evaluation.

In addition to cost accounting, the Phase I RPO evaluation should explain any significant cost increases and identify potential O&M savings. These recommendations should be included in the annual RPO report described in Section 2.3.

2.3 ANNUAL PHASE I RPO REPORTING

The annual Phase I performance report has three primary purposes:

TABLE 2.1
EXAMPLE RDL COST ACCOUNTING SPREADSHEET
FOR PUMP AND TREAT SYSTEM

<u>Annual O&M Costs</u>	<u>Unit</u>	<u>No. of Units</u>	<u>Unit Cost</u>	<u>Annual Subtotal</u>
Operations Labor	hr	1,560	\$50	\$78,000
Maintenance Labor	hr	416	\$50	\$20,800
Monitoring Labor	hr	104	\$50	\$5,200
AF Mgt Labor*	hr	80	\$60	\$4,800
Electricity	kwhr	110,000	\$0.06	\$6,600
Supplies	lump sum	1	\$5,500	\$5,500
Equipment Replacement (list)				
- Submersible Pump	ea	1	\$2,000	\$2,000
- New Controller	ea	1	\$6,500	\$6,500
- New pH Meter	ea	1	\$1,500	\$1,500
<u>Analytical Costs</u>				
Groundwater (SW8240)	ea	20	\$120	\$2,400
Influent/Effluent (SW8240)	ea	24	\$120	\$2,880
Air Monitoring (TO-14)	ea	12	\$150	\$1,800
<u>Administrative</u>				
Project Mgt Labor	hr	48	\$70	\$3,360
Reporting Labor	hr	48	\$60	\$2,880
RPO Phase I Labor	ea	24	\$50	\$1,200
Discharge Fees	lump sum	1	\$1,000	\$1,000
Administrative Supplies	lump sum	1	\$1,200	\$1,200
Annual Total				\$147,620.00

* Estimate provided by AF site manager.

- To provide an organized summary of system performance and cost data;
- To provide a formal evaluation of the remediation progress that can be reviewed by responsible DoD-site managers; and,
- To provide a document that identifies or recommends system improvements/optimizations and rec-

ommends more detailed Phase II evaluations when needed.

Annual Phase I performance evaluations should be prepared by the site manager or operating contractor at least 4 months before the deadline for annual budget requests. This will provide time for Phase I recommendations which require funding to be presented to the MAJCOM or appropriate headquarters. If annual performance evaluations are

already being provided to a regulatory agency, the Phase I performance evaluation should be combined with this report. Results of the Phase I evaluation can be documented using a simple letter report format that is customized for the specific remedial system being evaluated. Print-outs of performance and cost data should be provided as an attachment. An example letter report outline for a Phase I RPO evaluation of an SVE system is provided in Figure 2.3.

2.4 IMPLEMENTATION OF PHASE I RECOMMENDATIONS

Phase I RPO evaluations are not intended to be detailed studies of alternative regulatory approaches or replacement technologies. Instead, Phase I recommendations should focus on optimization of the existing remedial system and should focus on activities that can be completed without external contracting or regulatory negotiations. Under CERCLA and UST regulations, improvements to existing remediation systems such as flow adjustments and modification of extraction wells and above-ground treatments systems can be completed without extensive regulatory review. Optimizations that improve the effectiveness of an existing system can generally be implemented without regulatory approval, although informing the

regulatory agency of improvements is always advisable. RCRA permits are more stringent when it comes to changes to approved corrective actions. A Class I permit modification (generally a letter request) is required for most optimization activities involving an existing treatment system. Deletion of extraction wells or monitoring wells, changes in site monitoring plan, or changes in technologies may require a more detailed Class II or Class III permit modification. A positive working relationship with regulatory officials and providing them with a copy of the Phase I performance evaluation can improve the speed of implementing good ideas.

2.5 WHEN TO RECOMMEND A PHASE II EVALUATION

The Phase I evaluation should conclude with a recommendation either to continue operating the system for another year, with minor alterations/ optimizations, or to initiate a Phase II RPO evaluation. More detailed Phase II RPO evaluations should begin at least 18 months prior to 5-year ROD reviews, RCRA permit reapplications, or OPS demonstrations, or when the Phase I evaluation concludes that the remediation system is obviously falling short of established performance criteria. Sig

FIGURE 2.3 EXAMPLE PHASE I LETTER REPORT OUTLINE

1.0 Site Overview

- 1.1 Remedial Action Objectives
- 1.2 Remedial System Description

2.0 Protectiveness Evaluation

- 2.1 Current Protectiveness of Remedy
- 2.2 Current Regulatory Compliance

3.0 System Performance Evaluation

- 3.1 SVE Influent VOC Concentration and Flow Rate Trends
- 3.2 VMP (*In Situ*) Concentration Trends
- 3.3 Vacuum Influence Overlay
- 3.4 Mass Removal Estimates
- 3.5 Progress Toward Cleanup Milestones/Closure Criteria
- 3.6 Vapor Treatment Effluent vs. Discharge Limits

4.0 Cost Evaluation

- 3.1 Summary Table of Annual O&M Costs
- 3.2 Explanation of Cost Increases/Decreases

5.0 Recommendations

- 5.1 Optimization Activities
- 5.2 Cost Avoidance Opportunities
- 5.3 Need for Phase II RPO Evaluation

Attachment – Performance Tracking Tool Data Sheets

nificant changes to the conceptual site model (e.g., a new source area is identified) or opportunities to revise site cleanup goals may also trigger a Phase II evaluation. Examples of major deficiencies and inefficiencies include:

- A trend of increasing contaminant concentrations or significant "re-

bounding" at any location (see Section 3.5);

- Lack of contaminant containment when migration could lead to human or ecological exposure;
- A significant reduction in mass removal rates since the last Phase I evaluation;

-
-
- Asymptotic concentration levels above the desired cleanup goal;
 - Violation of discharge limitations;
 - Excessive O&M or monitoring costs;
 - Inappropriate cleanup goals, which are not based on site-specific risks.

If any of these indicators (or other site-specific indicators) are observed, the site manager should confer with technical specialists to determine if a Phase II RPO evaluation should be scheduled. If the annual Phase I report recommends a Phase II RPO evaluation to address major system deficiencies and inefficiencies,

then Phase II should commence as soon as possible. Prioritizing sites for Phase II evaluation can be based on several factors. For example, a small pump-and-treat system, which is expected to achieve cleanup criteria within the next five years, or is relatively inexpensive to operate should have a lower priority for a Phase II evaluation than a large pumping system which is plagued with poor performance and high costs. Each facility or MAJCOM should maintain a priority listing for Phase II RPO project funding.

SECTION 3 – DETAILED PHASE II EVALUATIONS

3.1 OVERVIEW OF PHASE II ACTIVITIES

The Phase II RPO evaluation will normally be performed by an experienced team of DoD, regulatory, and independent contractor personnel, as described in Section 1.2. The composition of the team will depend upon the specific remediation system and level of regulatory oversight. An example statement of work for obtaining contractor assistance for Phase II RPO evaluations is provided in Appendix B. Regardless of the type of remediation system under review, the following common tasks should be completed during the Phase II evaluation:

- A review of the ultimate remediation goals for the site to ensure they are appropriate and reflect current regulatory options;
- A design review including the conceptual site model and performance criteria (or establishing criteria) that are clearly defined and measurable;
- A detailed review of performance and cost data;
- An evaluation of system effectiveness based on trends in performance data;

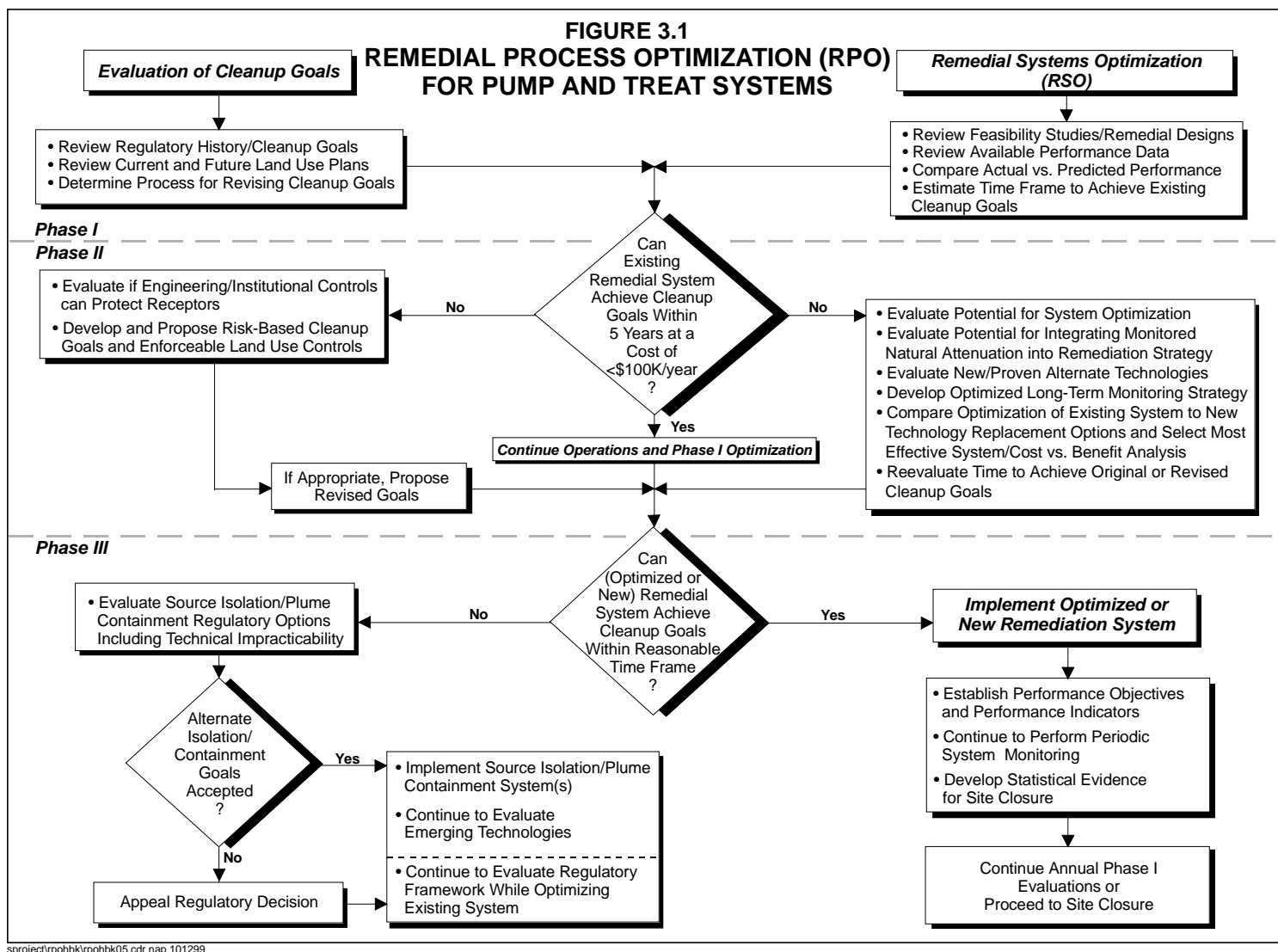
- An evaluation of system efficiencies and identification of optimization opportunities;
- Performing a cost-benefit analysis for recommended changes; and,
- Preparation of a Phase II report recommending new regulatory approaches, system optimizations, or new technology(ies).

Figure 3.1 provides an example of a flowchart for completing a Phase II RPO evaluation for a large groundwater pump-and-treat system.

3.2 REVIEW OF EXISTING REMEDIATION GOALS

A clear understanding of the goals and objectives of a remediation project is an essential first step in the optimization process. Remediation projects often lose continuity due to staff turnover in DoD and regulatory agencies, and changes in operating contractors. Because it is impossible to judge the success or failure of a remediation project without clearly defined goals, the RPO evaluation must begin here.

An understanding of the original remediation goal by the site manager and the O&M contractor is required to



evaluate the merit of remediation goals in light of changing site conditions - and new regulatory approaches. The purpose of this section is to provide a brief summary of underlying goals behind three common regulatory programs: RCRA, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and state underground storage tank (UST) rules. While an understanding of site cleanup goals is essential for both Phase I and Phase II RPOs, revision of cleanup goals will generally require a Phase II level of effort and a significant regulatory coordination. Section 4 describes opportunities for modifying cleanup goals using alternate concentration limits, updated toxicity information, site-specific, risk-based criteria, and other innovative approaches. Section 3.3.3 describes site conditions that limit the ability of remediation systems to achieve numerical cleanup goals, and regulatory options for sites where these conditions occur.

Before initiating systems optimization, the Phase II RPO evaluation team should carefully review the key decision documents for the site. These could include remedial investigation/feasibility study (RI/FS) reports, risk assessment summaries, remedial action plans, RODs, RCRA corrective action program

records, and correspondence between the regulatory community and the DoD facility.

Regulatory Participation - Site remediation goals are closely tied to the regulatory framework under which site remediation is being implemented. A good working relationship with local regulators will be an important component of a successful RPO evaluation. If significant changes to remediation goals or the remedial approach are needed, a technical expert from the responsible regulatory agency should be included as a member of the Phase II RPO team.

3.2.1 RCRA Sites

RCRA was established in 1976 to regulate hazardous wastes being generated at active industrial and government facilities, and to provide “cradle to grave” management of hazardous wastes. Although EPA provides overall direction for this program, much of the oversight and enforcement of RCRA has been delegated to state agencies. RCRA is generally enforced at active facilities where hazardous wastes are being managed or disposed of, or were inadvertently released after 1980. Fuels are generally excluded from the “hazardous waste” definition so long as they are not mixed with another hazardous waste.

Disposal or spill areas are known as "solid waste management units."

A primary goal of RCRA is to ensure that hazardous wastes do not migrate from, and present a risk to human populations or the environment outside of, the solid waste management unit. To ensure protectiveness, RCRA requires that point-of-compliance wells be established and routinely monitored. RCRA defines the point of compliance as "...a vertical surface located at the hydraulically downgradient limit of the waste management area that extends down into the uppermost aquifer underlying the regulated unit." Any detection of hazardous waste at the point-of-compliance above the permitted groundwater protection standard, can trigger the need for corrective action.

Many DoD sites are involved in RCRA corrective action programs that seek to remove or reduce the source of hazardous waste, limit further groundwater contamination, and restore contaminated groundwater that has migrated beyond point-of-compliance well(s). Cleanup goals for RCRA sites are known as "groundwater protection standards" and soil cleanup criteria are often directly related to preventing the formation of leachate that exceeds groundwa-

ter protection standards. RCRA Subpart 264.94 provides rules for setting concentration limits for hazardous constituents. Federal maximum contaminant levels (MCLs) or state groundwater quality standards for drinking water have frequently been used as point-of-compliance concentration limits. It is important to point out that Subpart 264.94 (a)(3) allows the facility owner to propose "alternate concentration limits (ACLs)" at sites where the hazardous compound(s) will "not pose a substantial present or potential hazard to human health or the environment as long as the ACL is not exceeded."

Changes to groundwater protection standards can be proposed at any time; however, proposing an ACL will generally require a modification to the existing RCRA permit and approval by the EPA Regional Administrator. Section 4.1 offers additional information on proposing revised cleanup goals under RCRA.

3.2.2 CERCLA Sites

CERCLA was enacted in 1980 with the primary purpose of cleaning up inactive and abandoned waste sites and assigning financial liability for cleanup. This program is primarily administered by EPA through the National Contin-

gency Plan (NCP), which specifies a systematic method of site identification, a hazard ranking system, RI/FS procedures leading to a ROD and remedial action. The DoD Installation Restoration Program (IRP) was developed to assist the DoD in complying with NCP requirements.

At DoD facilities, CERCLA regulations have generally been applied at abandoned industrial waste disposal sites, landfills, radioactive sites, and leaks from storage tanks containing non-fuel hazardous substances, particularly if waste disposal or releases were known to occur before 1980. Fuel spills are specifically excluded under CERCLA, and generally are regulated under state UST programs (Section 2.1.3).

The primary goal of CERCLA is to reduce the risk that hazardous substances may pose to human health and the environment. To accomplish this goal, the current and potential future risks from hazardous substances in environmental media (e.g., soils, soil gas, and groundwater) are evaluated. A baseline risk assessment is performed that quantifies human cancer risks and non-cancer health hazards posed by individual and combined contaminants. Risks to ecological receptors are also determined.

Response actions are required at sites that present an imminent threat to human health or the environment. Such sites are given a high priority for funding of actions that will halt the exposure of humans or ecological receptors to contaminants. Sites that pose less immediate threats are evaluated using the same process, but are remediated when funding is available.

The process for establishing cleanup goals for CERCLA begins during the RI phase by considering conservative risk-based screening levels (RBSLs) and other applicable or relevant and appropriate requirements (ARARs). Revision of conservative RBSLs to site-specific values and identification of ARARs is an ongoing process throughout RI/FS activities. There are three kinds of ARARs -- chemical-specific, location-specific, and action-specific. Under CERCLA and the NCP (40 CFR 300.430), acceptable exposure levels are determined by ARARs. If ARARs are unavailable, risk-based remedial action objectives can be developed. Unfortunately, many CERCLA sites have been forced to use conservative, chemical-specific ARARs such as attainment of federal or state drinking water MCLs as groundwater cleanup goals. Contaminated groundwater at many of these sites is confined to shal-

low aquifers, which are often unproductive for domestic pumping or hydraulically separated from deeper production aquifers. In California, domestic use of water ("drinking water") is considered to be the highest beneficial use, and remediation to drinking-water standards is generally required because this affords the greatest level of protection and cleanup. Likewise, soil remediation standards are often based on residential scenarios that protect children and adults from cancer risks associated with a lifetime of exposure to contaminated soil.

It is very important that the RPO evaluation team understand the exposure assumptions that form the foundation for the site cleanup goals. These assumptions should be included in the ROD and RI/FS documents. There has been considerable controversy over the use of overly conservative exposure assumptions for establishing cleanup goals at industrial sites. Section 4.1 discusses recent regulatory changes that are promoting more realistic soil and groundwater remediation goals for sites in industrial and commercial areas.

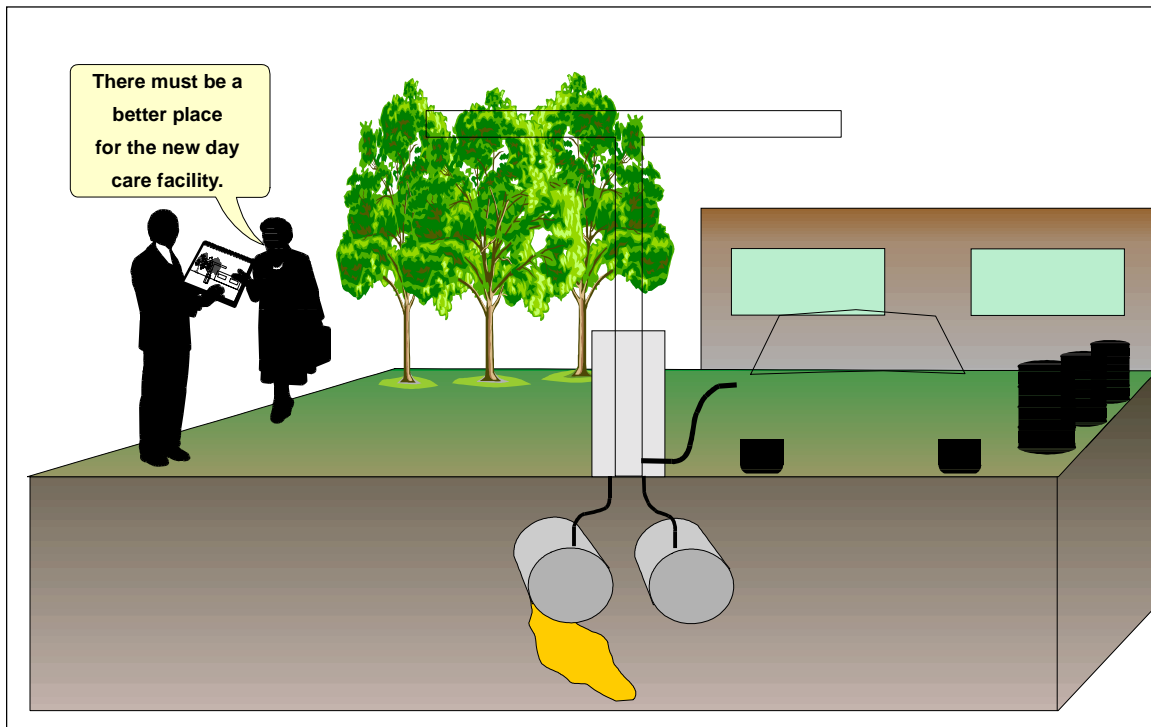
3.2.3 State UST Sites

As a result of the 1984 RCRA amendments, separate regulations were established for USTs. Because of the

enormous number of small UST sites, EPA delegated the responsibility for establishing guidelines for UST site characterization and remediation to state agencies. The decentralization of UST regulations resulted in significant inconsistencies in UST remediation requirements from state to state. Rather than attempting to review the magnitude of contamination and risk at each site, the majority of states opted to establish very conservative, generic cleanup criteria, such as the 100-milligram-per-kilogram (mg/kg) total petroleum hydrocarbon (TPH) standard for soil cleanup. Some states included all fuel storage facilities, including aboveground tanks and pipelines in their "UST" programs in an effort to provide consistency for petroleum site remediation.

Beginning in the early 1990s, many states began to realize that few petroleum release sites posed an immediate risk to human or ecological receptors, and that significant private and taxpayer monies were being spent for little risk-reduction benefit. Many state UST reimbursement funds were depleted with little to show in the way of health-protective remediation.

In 1992, AFCEE began two major technology demonstration programs at



more than 50 Air Force installations in the United States to encourage the widespread application of bioventing and monitored natural attenuation. In 1994, AFCEE initiated a risk-based site closure initiative, which combined the merits of natural attenuation, bioventing, and site-specific, risk-based cleanup criteria to streamline the site closure process.

The risk-based initiative picked up additional momentum when the American Society for Testing and Materials (ASTM, 1995) published RBCA guidance for petroleum-contaminated sites. This guidance was developed to provide

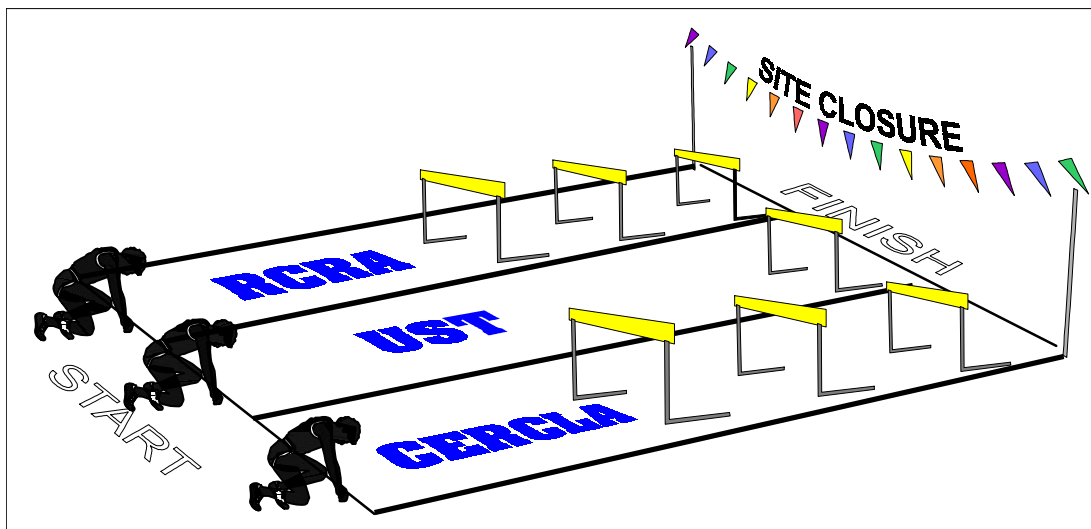
a more consistent and rational decision-making process for the remediation of petroleum-contaminated sites, and specifically for the thousands of contaminated gasoline stations across the United States. A three-tiered approach was designed to provide the site owner and regulatory agencies with a more consistent method of classifying sites as to the urgency and scope of cleanup required at each site. Today, nearly every state has adopted some form of risk-based remediation criteria for petroleum sites. Many states have developed chemical-specific and less stringent standards for

industrial/commercial land uses and are simplifying site closure standards.

3.2.4 Regulatory Optimization

Since 1984, many DoD facilities have removed fueling facilities from RCRA or CERCLA authority and placed them under state UST regulations. This regulatory optimization generally results in

significantly less "red tape" to obtain site closure (than under RCRA or CERCLA) and provides a variety of site-specific, risk-based cleanup options. If the site being evaluated has petroleum products as primary contaminants, the RPO team should consider the potential benefits of requesting a change from RCRA or CERCLA to state UST jurisdiction.



3.3 DESIGN REVIEW

The next step in the Phase II evaluation is to gain a detailed understanding of the existing treatment system and the assumptions behind its design. The RPO team should include experienced engineers and technicians familiar with the design and operating parameters of the type of remediation system being evaluated. Beginning with a review of site geological and contaminant conditions, the team should proceed with review of

feasibility/pilot study documentation and full-scale design documents.

3.3.1 Validate the Conceptual Site Model

Particular attention should be directed to site assumptions that influenced the design, such as: the uniformity of geologic formation; contaminant distribution; the predicted rate at which contaminants in the affected media (e.g., groundwater or soil gas) could be extracted; and discharge limitations. If a

subsurface conceptual site model (CSM) was not developed as a part of the initial design, or if the understanding of site conditions has changed significantly, the RPO team should develop a CSM based on the most recent operating and monitoring data. Monitoring data collected during system operations can provide significant insight in subsurface contaminant distribution and geological variations.

The CSM provides a visual summary of the physical, chemical, and biological characterization of the site. A CSM should describe site geology and hydrology; contaminant sources, properties, and migration; fate and transport processes; and current and future receptors. The CSM serves as the foundation for evaluating the restoration potential of the site and the effectiveness of the operating remediation systems. Figure 3.2 illustrates a typical CSM for a chlorinated-solvent-contaminated site. Once the RPO team understands the CSM and the design, the reviewers should focus on defining performance criteria and evaluating the effectiveness of the remediation system.

3.3.2 Define Performance Criteria

The Phase II RPO team should review and update the list of remediation performance criteria. Performance criteria

can be viewed as milestones on the road to achieving final site remediation goals and site closure. These milestones must be measurable and should relate to data that are routinely collected at the site. In some cases, these intermediate goals may have been established during the system design or are included in regulatory decision documents.

Unfortunately, many remediation systems are operating without clearly defined performance criteria, and there has been no organized effort to evaluate system effectiveness. In these cases, the RPO team should be responsible for defining some key performance criteria. Performance criteria will be site-specific. At most sites, performance will be measured by achieving a certain percentage-reduction in contaminant concentrations or volume of contaminated media over a specified time. For example, an SVE performance criteria might call for a 90-percent reduction in equilibrium benzene soil gas concentrations following one year of treatment.

**FIGURE 3.2
ELEMENTS OF A CONCEPTUAL SITE MODEL (CSM)**

Background Information

- Location of water supply wells.
- Ground-water classification.
- Nearby wellhead protection areas or sole-source aquifers.
- Locations of potential receptors exposure points.

Contaminant Source and Release Information

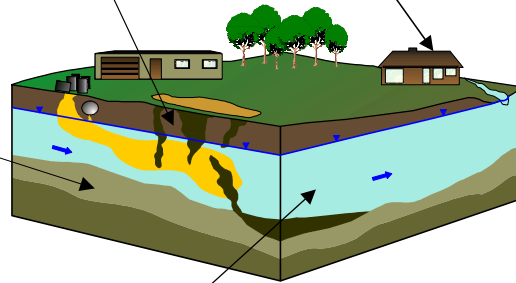
- Location, nature, and history of previous contaminant releases or sources.
- Locations and characterizations of continuing releases or sources.
- Locations of subsurface sources (e.g., DNAPLs).
- Flux of contamination from DNAPL.

Risk Assessment

- Current and future receptors.
- Exposure scenario's.
- Completed pathways?
- Exposure concentrations.

Geologic and Hydrologic Information

- Description of regional and site geology.
- Physical properties of subsurface materials (e.g., porosity, bulk density).
- Stratigraphy, including thickness, lateral extent, continuity of units, and presence of depositional features, such as channel deposits, that may provide preferential pathways for, or barriers to, contaminant transport.
- Geologic structures that may form preferential pathways for DNAPL migration or zones of accumulation.
- Depth to ground water.
- Hydraulic gradients (horizontal and vertical).
- Hydraulic properties of subsurface materials (e.g., hydraulic conductivity, storage coefficient, effective porosity) and their directional variability (anisotropy).
- Spatial distribution of soil or bedrock physical/hydraulic properties (degree of heterogeneity).
- Temporal variability in hydrologic conditions
- Groundwater recharge and discharge information.
- Groundwater/surface water interactions.



Contaminant Distribution, Transport, and Fate Parameters

- Properties of DNAPLs that affect transport (e.g., composition, effective constituent solubilities, density, viscosity).
- Phase distribution of each contaminant (gaseous, aqueous, sorbed, free-phase DNAPL or residual DNAPL) in the unsaturated and saturated zones.
- Spatial distribution of subsurface contaminants in each phase in the unsaturated and saturated zones.
- Estimates of subsurface contaminant mass.
- Temporal trends in contaminant concentrations in each phase.
- Partitioning coefficients and migration rates.
- Contaminant natural attenuation processes (destructive and non-destructive).

Source: Adapted from EPA, 1993.
sprojectrphobk/rphobk06.cdr nap 101299

At sites with difficult to remove sources (e.g., NAPLs or landfill wastes) effectiveness will be measured by the success in limiting plume migration or controlling soil gas emissions. At BRAC sites, the achievement of these intermediate milestones should lead to a OPS demonstration that will allow the site to be transferred to a new landowner. Performance criteria could also include a goal to reduce the area of the site that must remain under restrictive institutional controls. Performance criteria for aboveground treatment systems also requires complying with the discharge limits placed on effluent contaminant concentrations.

3.3.3 Site Conditions that Limit Potential for Remediation

There are several types of sites that are particularly difficult to fully remediate (Figure 3.3). These site limitations will often require a source containment/isolation approach if source removal is not possible.

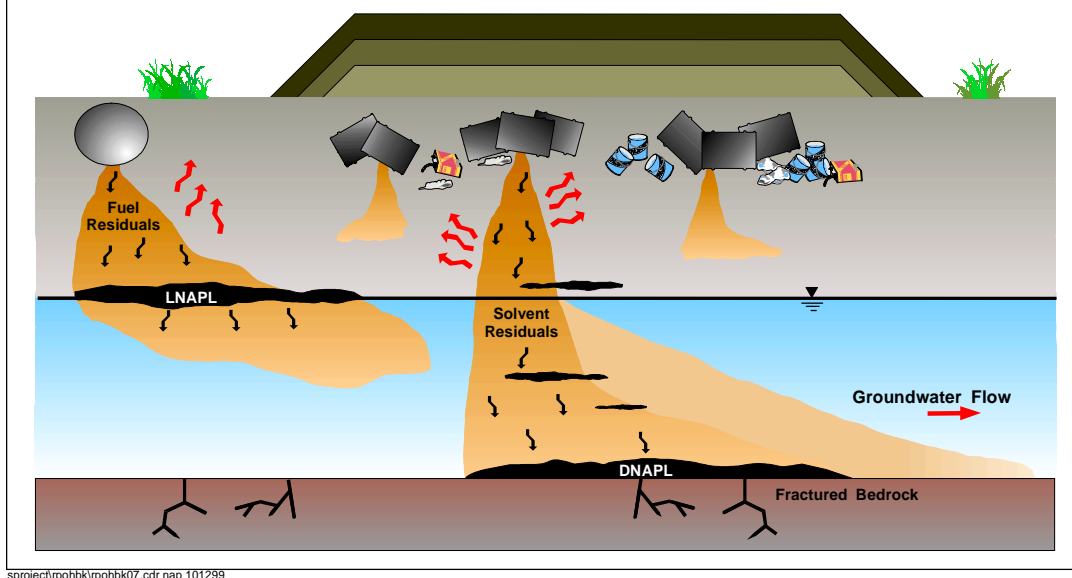
Low Permeability and Heterogeneous Sites – Low permeability and very heterogeneous soils hinder the uniform flow of groundwater and soil gas required for timely remediation. Migration of contaminated groundwater and DNAPL into fractured bedrock also can pose an obstacle to remediation. The

RPO team should be aware of subsurface conditions that are likely to impact the remediation process. Sampling of low-permeability layers may be required to ensure that the observed treatment is not occurring in high-permeability zones while bypassing low-permeability soils or aquifer material.

Nonaqueous-Phase Liquid (NAPL)

– NAPL includes both dense NAPLs (DNAPLs) such as chlorinated solvents and light NAPLs (LNAPLs) such as petroleum products. Pure liquids often saturate soils and make it difficult for water or air to impact the most concentrated contamination on the site. While the toxicity of petroleum product is known to decrease overtime, this is not always the case with chlorinated solvents such as trichloroethylene. Because complete removal of NAPLs is generally impossible, NAPL-contaminated sites could require centuries of conventional treatment. Section 4.2.5 discusses requirements for obtaining TI waivers and implementing limited pumping or other containment technologies at NAPL sites. Innovative technologies such as in-situ thermal treatment, chemical oxidation and surfactant addition may be able to reduce the long-term impact of DNAPL sources and should be considered at sites with high-permeability soils.

FIGURE 3.3
COMMON LIMITATIONS TO SITE CLEANUP



Landfills – Domestic and industrial landfills typically contain concentrated waste, from which metals and organic contaminants can leach to groundwater. Because the precise location and quantity of hazardous materials is generally unknown, and because safety hazards are common, source removal typically is not attempted at landfills, and impermeable caps are placed over the waste areas to reduce leachate formation. Hence, most landfills are contained and not remediated. Because the source of dissolved contamination is not removed, leachate collection and treatment systems may be required to operate indefinitely. These systems can present significant optimization opportunities be-

cause even small O&M savings are compounded over decades of operation.

Containment and Isolation Strategies - At most landfill sites and many sites contaminated with DNAPLs, the source of contamination can not be removed or significantly reduced. At sites with high-permeability soils, pilot testing of DNAPL reduction technologies such as in-situ thermal treatment, chemical oxidation, or surfactants is recommended as a possible method of reducing the source or areal extent of the plume. Despite progress in source reduction technologies, the attainment of conservative cleanup goals, such as MCLs, at all locations at these sites is generally impossible. Fortunately, most regulatory agencies acknowledge this

fact, and are now offering alternatives to total site cleanup. Contaminant containment and isolation strategies are becoming increasingly popular at these sites and should be carefully considered as alternatives to active remediation systems for most landfill and many sites contaminated with DNAPLs.

3.4 COLLECTING ADDITIONAL SYSTEM PERFORMANCE DATA

The goal of the annual Phase I RPO evaluation is to collect and assemble data that can be easily accessed for more detailed Phase II evaluations and to support of 5-year ROD reviews and OPS demonstrations (see Section 2.1). While visiting a site, the RPO team should request a listing of the types of monitoring data that are being collected at the site and where these data are available for review. (If data is difficult to access, the RPO team should recommend the establishment of a performance tracking database (See Appendix F example).

Equilibrium Data - In addition to the standard data collected during Phase I evaluations, equilibrium data are particularly important when evaluating pumping systems and other *in situ* treatment systems such as SVE, bioventing, and air sparging. To collect equilibrium data, all or part of the treatment system must be turned off so that contaminants that

are sorbed or trapped within the soil matrix have an opportunity to equilibrate with the surrounding groundwater or soil gas. (This level of testing may be completed under Phase II RPO evaluations.) Equilibrium data give a more accurate picture of how site contaminants in the entire soil/soil gas or soil/groundwater system are decreasing in comparison to initial (pretreatment) equilibrium levels. The time period required to reach equilibrium is contaminant- and site-specific. In general, soil gas can be expected to equilibrate within 3 to 6 weeks, while groundwater may require several months. For SVE or bioventing systems, the site-specific equilibrium period can best be estimated by using a handheld volatile organic compound (VOC) analyzer to determine when concentrations of soil gas VOCs have "leveled off" at vapor monitoring points (VMPs). For groundwater extraction systems, monthly collection of samples from source area monitoring wells will be required to assess contaminant equilibrium. If equilibrium data have not been gathered during the initial years of treatment, the RPO team should determine if the system could be turned off so that equilibrium data could be collected for evaluation. If plume containment is a concern, only wells in the source area should be turned off for equilibrium testing. Figures 3.4 and 3.5 illustrate the typical "rebound"

of contaminant concentrations during equilibrium testing.

3.5 EVALUATION OF SYSTEM EFFECTIVENESS

There are two primary criteria to be addressed in a remediation system evaluation: effectiveness and efficiency. System *effectiveness* refers to the ability of the system to achieve the remediation goals at a given site. For example, if plume remediation is the primary goal for the site, system effectiveness will be measured by the mass of contaminant removed from the aquifer and the permanent decrease in concentrations at plume monitoring wells. At a fuel-contaminated site, effectiveness could be measured by the rate at which benzene (or another contaminant of concern) is being removed from the soil by a bio-venting or SVE system.

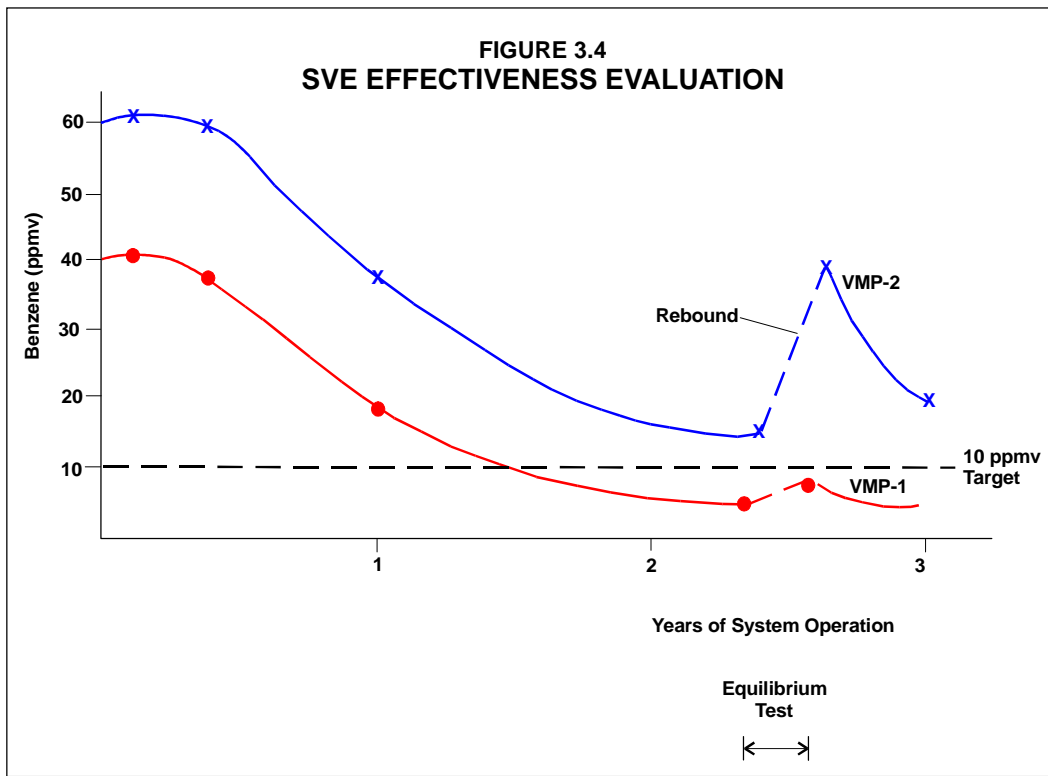
The first and primary focus of the RPO team should be to determine if the existing technology is capable of achieving remediation goals within a reasonable time frame. While it is tempting to “jump into” system-efficiency improvements, this phase of the RPO evaluation should not begin until the fundamental effectiveness of the existing technology has been validated.

System *efficiency* refers to the optimization of time, energy, and costs associ-

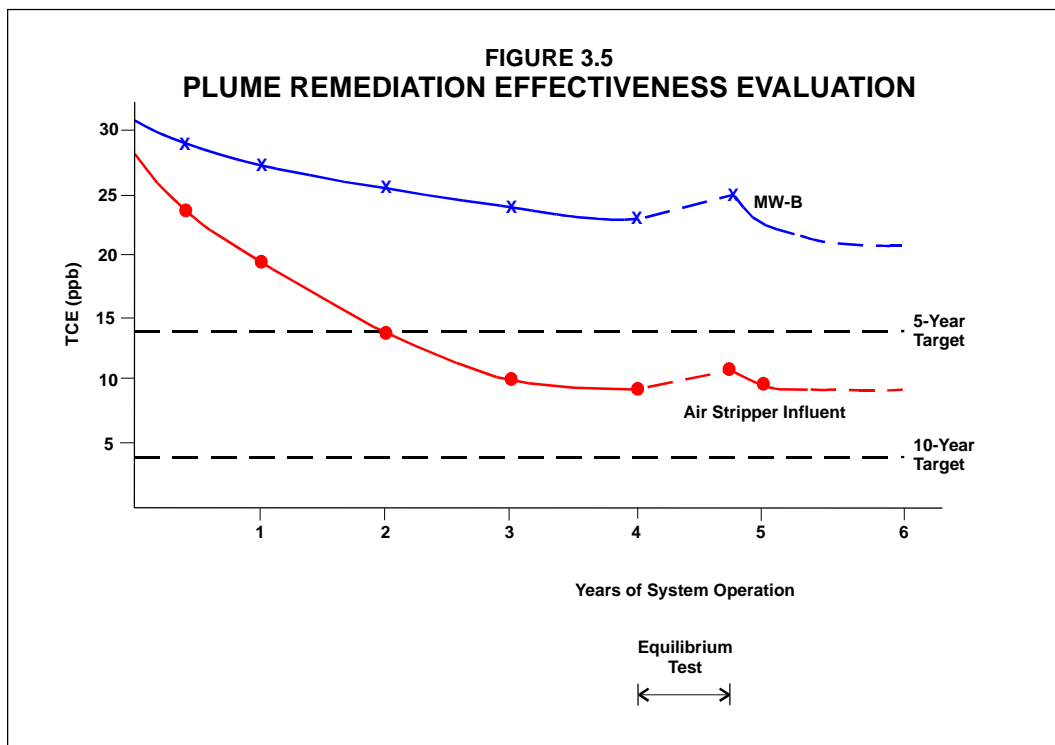
ated with achieving remediation effectiveness using a specific technology. For example, a groundwater pump-and-treat system may be reducing contaminant concentrations, but pumping at excessive rates. This results in system inefficiencies such as high O&M costs and the over design of aboveground treatment units. Section 3.6 describes how to improve the efficiency and “optimize” common technologies in use at DoD sites.

Effectiveness evaluations can best be completed by direct comparison of actual performance data to established performance criteria. Illustrations such as charts, graphs, and overlay maps provide the most useful tools for evaluating these data. When evaluating treatment effectiveness it is important to graph data from several locations at the site, as well as treatment system influent data. Contaminant concentrations at monitoring points in the source area, in the impacted soil and groundwater plume, and from wells at the perimeter of contamination should be plotted. For more complex sites, contaminant levels at several depths may require the use of a 3-dimensional graphics package.

The following performance evaluations are recommended for several different technology groups that are often



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combined for site remediation. Detailed system evaluation checklists for over 20 of the most common remediation system components have been developed by the US Army Corps of Engineers and are listed in Section 3.5.8. Example checklists and USACE website information is included in Appendix C. The RPO evaluation team can use these checklists to collect important information on system effectiveness.

3.5.1 Extraction Systems

While most *in situ* extraction systems can remove contaminants that are dissolved in groundwater or are volatilized in soil gas, they are limited in their ability to remove contaminants that are sorbed to, or trapped within, the soil matrix. This situation is known as "diffusion limited" removal and is the most common shortfall of *in situ* soil and groundwater extraction systems. Figure 3.4 illustrates a typical contaminant-reduction curve for extraction technologies such as SVE. Reductions in equilibrium levels of benzene indicate that progress is being made at this site; however, the performance criteria of achieving a 10-part-per-million-by-volume (ppmv) equilibrium concentration within 3 years has not been achieved in the source area monitoring point (VMP-2). Soils near VMP-2 are experiencing dif-

fusion-limited removal because under normal operations, the rate of benzene desorption or travel through low-permeability soils is limiting the rate of benzene removal. If rapid remediation is required at this site, another approach to soil remediation (e.g., excavation or thermal enhancement) may be needed for the soil volume near VMP-2.

Figure 3.5 illustrates a contaminant-reduction curve for a groundwater pumping system. TCE concentrations have reached near asymptotic levels in the influent to the air stripper however, MW-B has had much higher levels of TCE and a slower rate of reduction. The effectiveness of this system could possibly be improved by increasing pumping rates near MW-B and decreasing pumping rates near the wells at which the 5-ppb cleanup objective has been achieved.

If little or no NAPL is present, and site soils are sufficiently permeable to allow air or groundwater flow, extraction technologies will often achieve cleanup goals in a reasonable time frame. If residual NAPL is trapped in the soil matrix or soils are not permeable, diffusion limitations may result in unacceptably long cleanup times. Significant rebounding of contaminants in source area wells during equilibrium testing is one indication that NAPLs may be present in

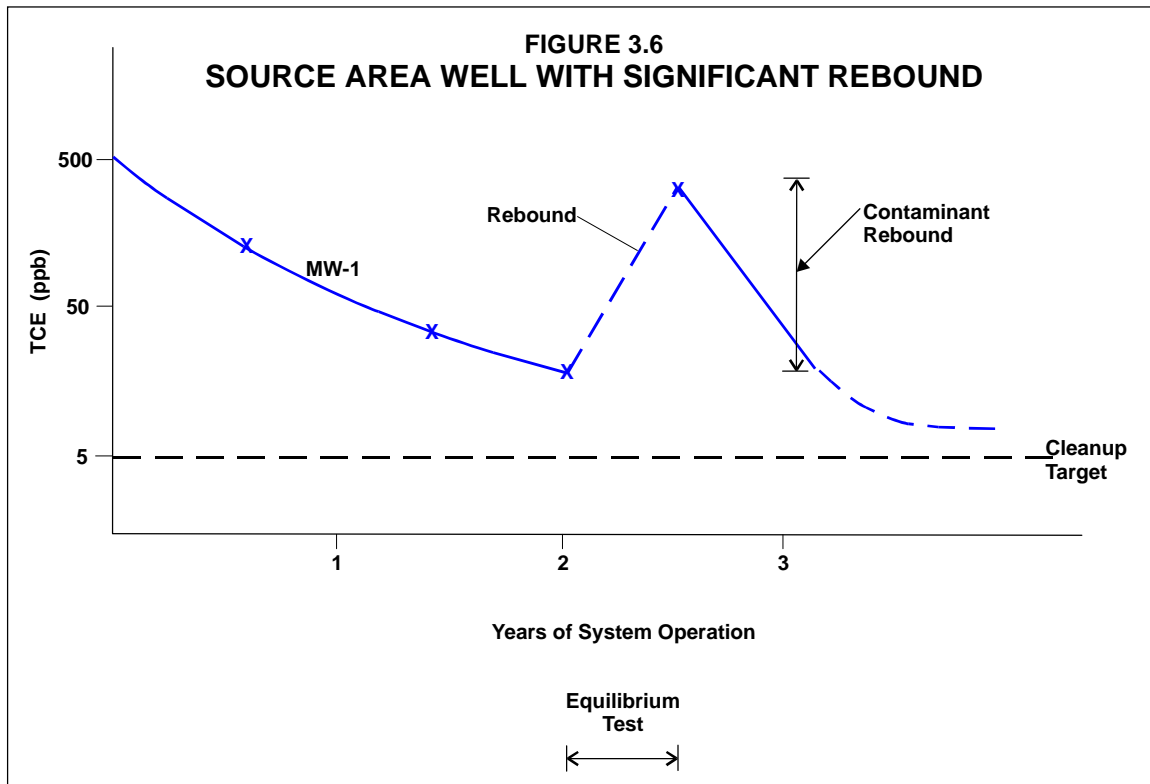
soils or aquifer material. Rebounding can also indicate an area of inefficient treatment where residual contamination is not being impacted by the treatment technology. Figure 3.6 illustrates significant rebounding in source area well MW-1. This situation may require a re-evaluation of the system design, or possibly a change of cleanup goals to emphasize source containment rather than total plume remediation.

3.5.2 NAPL Recovery Systems

Limited options are available for NAPL recovery, and no technologies have been consistently effective at removing significant percentages of NAPL from saturated soils. Even aggressive technologies such as dual-phase extraction have been unable to achieve complete cleanup of LNAPLs. The RPO evaluation should consider other options for free-product, such as a risk-based approach that documents natural weathering. A recent study completed by AFCEE entitled *LNAPL Weathering at Various Fuel Release Sites* examined the natural weathering of BTEX compounds at five jet fuel sites. The study indicated a first-order weathering rate (and risk reduction) for benzene of 26 percent per year. The effectiveness of natural weathering at reducing toxic compounds should be considered in the effectiveness evaluation. Excavation and removal also

should be considered at sites where product removal is a regulatory requirement and excavation of fuel-saturated soils is feasible and cost-effective.

Because DNAPLs often migrate below the water table, they are particularly difficult to locate in layered soils or fractured bedrock. Even when they are located, there is currently no technology available for completely removing DNAPLs from the subsurface (except excavation of shallow impacted soils). Recent advances in thermal treatment, chemical oxidation, and surfactant flushing are improving DNAPL removal at some sites. However, even if 95 percent of DNAPL could be removed and the plume size reduced, the source area groundwater would remain contaminated above MCLs for decades at most sites (Freeze and McWhorter, 1997). The presence of DNAPLs is normally confirmed by the inability of pumping to reduce equilibrium levels in source area wells. If this is occurring, and there is no promising source reduction technology available for pilot testing, the RPO evaluation team should identify the site as a candidate for source containment based on the technical impracticability of attaining cleanup goals at the source. Section 4.2.5 provides additional guidance on TI waivers.



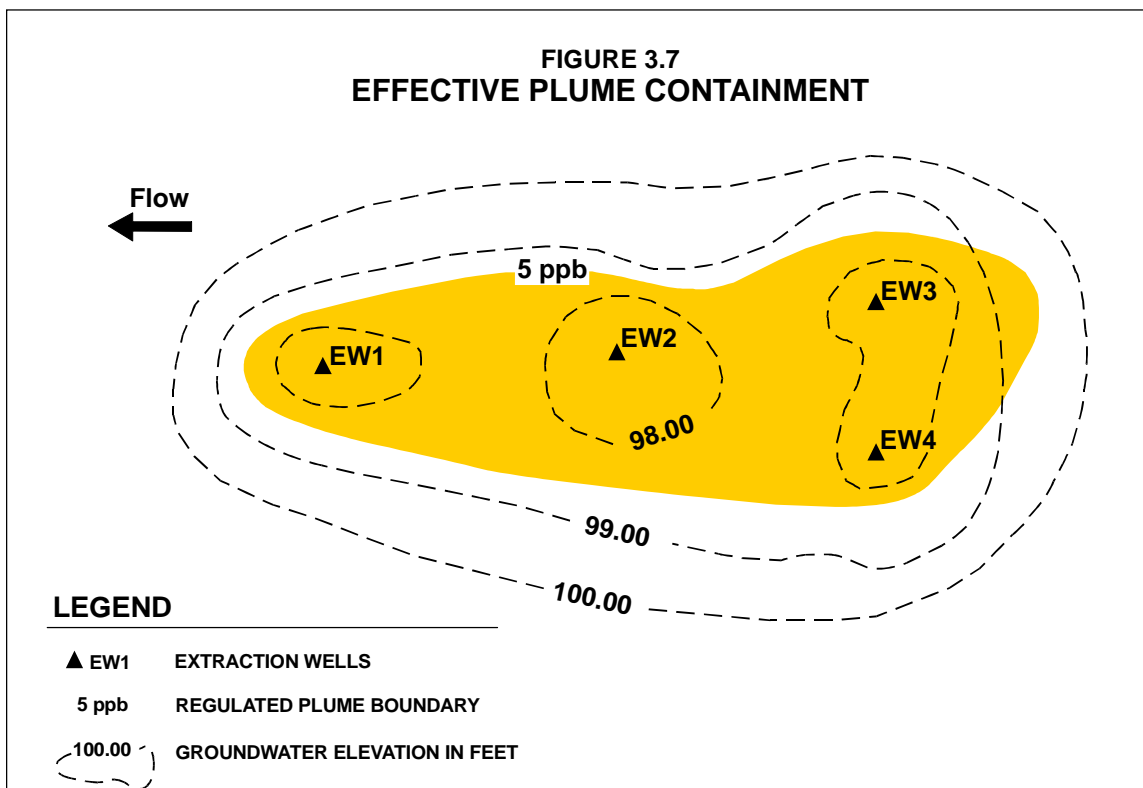
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3.5.3 Pumping Containment Systems

Evaluation of the effectiveness of groundwater containment systems will require a careful analysis of water levels surrounding the pumping system and of contaminant trends, particularly at wells located at the plume perimeter. Figure 3.7 shows typical groundwater draw-down at a pump-and-treat site with the current TCE plume superimposed. Hydraulic containment appears to be effective at this site. In a containment scenario, TCE concentrations in the plume perimeter wells should steadily decrease. Theoretically, the quantity of water pumped from the aquifer should de-

crease over time as pumping is focused closer and closer to the source area.

The EPA (1994) publication, *Methods for Monitoring Pump-and-Treat Performance* is particularly useful in evaluating the effectiveness of both contaminant extraction and hydraulic containment. The EPA Technology Innovation Office (TIO) has demonstrated that the MODMAN model is particularly effective for determining containment effectiveness under a variety of pumping scenarios. Other models such as MODGA and MODFLOW can be used to simulate pumping containment.



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3.5.4 *In Situ* Treatment Systems

The effectiveness of *in situ* treatment methods such as bioventing can be evaluated by direct or indirect measurements. Soil or equilibrium soil gas samples can be collected to demonstrate mass removal. Indirect measurements such as microbial oxygen utilization can be used to provide qualitative indications of the hydrocarbon levels remaining in surrounding soil. Indirect measurements often can be used to determine when more expensive or intrusive sampling should be scheduled to verify contaminant removal. The *Air Force Bioventing*

Principles and Practice Manual (AFCEE, 1997) and the *AFCEE Guidance on Soil Vapor Optimization* (AFCEE, 2001) contain useful information for evaluating bioventing and other *in situ* treatment technologies.

3.5.5 Aboveground Treatment Systems

A variety of aboveground treatment systems are installed at military installations, primarily to remove or destroy contaminants contained in extracted groundwater or soil gas. Common groundwater treatment systems include air stripping for VOCs and activated

carbon for removal of semivolatile hydrocarbons and for polishing air stripper effluent. At sites contaminated with dissolved metals, ion exchange and precipitation processes are frequently employed. Common soil gas treatments include activated carbon and a variety of thermal treatment methods. For each of these aboveground treatment technologies, effectiveness is measured by the ability of the technology to remove contaminants from the extracted groundwater or soil gas so that discharge limits are not exceeded. Aboveground systems can be modified or new technologies can be substituted to maintain the required removal effectiveness. Most RPO evaluations of aboveground treatment systems will focus on improving efficiency through modifications to existing systems or replacement with another technology.

3.5.6 Monitoring Systems

An effective monitoring system will provide the site engineer with both short-term feedback on the effectiveness of individual aboveground or *in situ* treatment systems, and long-term feedback on the effectiveness and protectiveness of the overall site remedy. Influent and effluent monitoring points should be established for individual treatment systems to determine treatment efficiency and to ensure that the system is effec-

tively meeting regulatory discharge standards. For many systems, this will include frequent calibration of both hand-held monitoring and flow measurement devices, and careful adherence to the field sampling and analysis plan to ensure accurate and reproducible data.

The effectiveness and protectiveness of the overall site remedy is generally monitored at groundwater wells and soil VMPs. These monitoring points must be located so that the remediation response of the entire contaminated soil and/or groundwater volume can be accurately estimated by the monitoring network. An effective monitoring system will reduce the level of uncertainty regarding the spatial and temporal distribution of contaminants. Although a complete description of how to establish effective monitoring networks is beyond the scope of this document, three references are recommended: the *AFCEE Long-Term Monitoring Optimization Guide* (Appendix D), the *AFCEE Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Groundwater*, and the *AFCEE Bioventing Principles and Practice Manual*.

An effective monitoring network should:

-
-
- Bound the horizontal and vertical extent of contamination and be able to define concentration gradients, including defining an approximate "non-detect" boundary;
 - Measure the rate and direction of any contaminant migration to confirm containment or noncontainment;
 - Measure the decrease in contaminant concentration resulting from treatment and estimate the mass of contaminant reduction in the subsurface;
 - Determine if the source area is decreasing in concentration or how residual contamination may be limiting the rate of treatment.

3.5.7 Estimating Time To Achieve Remediation Goals

The estimated time to achieve remediation goals will dictate the total cost of the project and should be updated during the Phase II RPO evaluation. Although RI/FS and remedial design documents attempt to predict the time required to reduce contaminant concentrations to cleanup goals, these estimates are often based on limited pilot-test results and unverified assumptions concerning contaminant distribution, hydrogeology, etc. Once the remedial system has operated for several years, these estimates should

be refined as a part of the RPO effectiveness evaluation.

Modeling Approach

Most remedial designs for large pump-and-treat and SVE systems include use of a mathematical model to predict the time that will be required to reduce contaminant concentrations to remediation standards. If the input assumptions and numerical code for the original model are available, an experienced modeler should review the input assumptions and compare actual observed pumping (or airflow) rates, capture zones, and contaminant recovery rates to the original model assumptions. The RPO team can then produce a refined model that more accurately predicts future performance.

In some cases, the original model is unavailable or may be judged to be inappropriate for existing site conditions. If the cleanup time is critical to the RPO evaluation, a new state-of-the-art model should be developed for the site. Information on hydraulic control, solute transport, and SVE models can be found on the EPA website www.epa.gov/ada/kerrcenter.html (csmos directory).

Observational Approach

At pump-and-treat sites with 5 or more years of operation (6-12 months for SVE systems), cleanup times can often be estimated from site monitoring data without complicated modeling. This "observational approach" to estimating remediation time is preferred over modeling because it is based on actual contaminant removal rates over time rather than predictions based on unverified assumptions. Additional information on monitoring aquifer restoration can be found in the EPA (1994) publication, *Methods of Monitoring Pump and Treat Performance*. For pump-and-treat systems, the following observations can be used to estimate remediation time frames.

- Based on the potentiometric surface of the groundwater, confirm that the entire contaminated plume is within the capture zone.
- Plot contamination versus time for each monitoring point and extraction well. Figure 3.8 illustrates a situation where the system is approaching asymptotic recovery at all monitoring wells. Using observed data, a simple first-order equation can be solved to estimate the time to attain the 5-ppb cleanup goal.

- Figure 3.6 illustrated a situation where significant rebound is occurring at source area well MW-1, suggesting that DNAPL or LNAPL may be present in the source area. The time frame for achieving cleanup goals is difficult to estimate at these sites. This site may be a candidate for a TI waiver or minimum pumping for source containment.

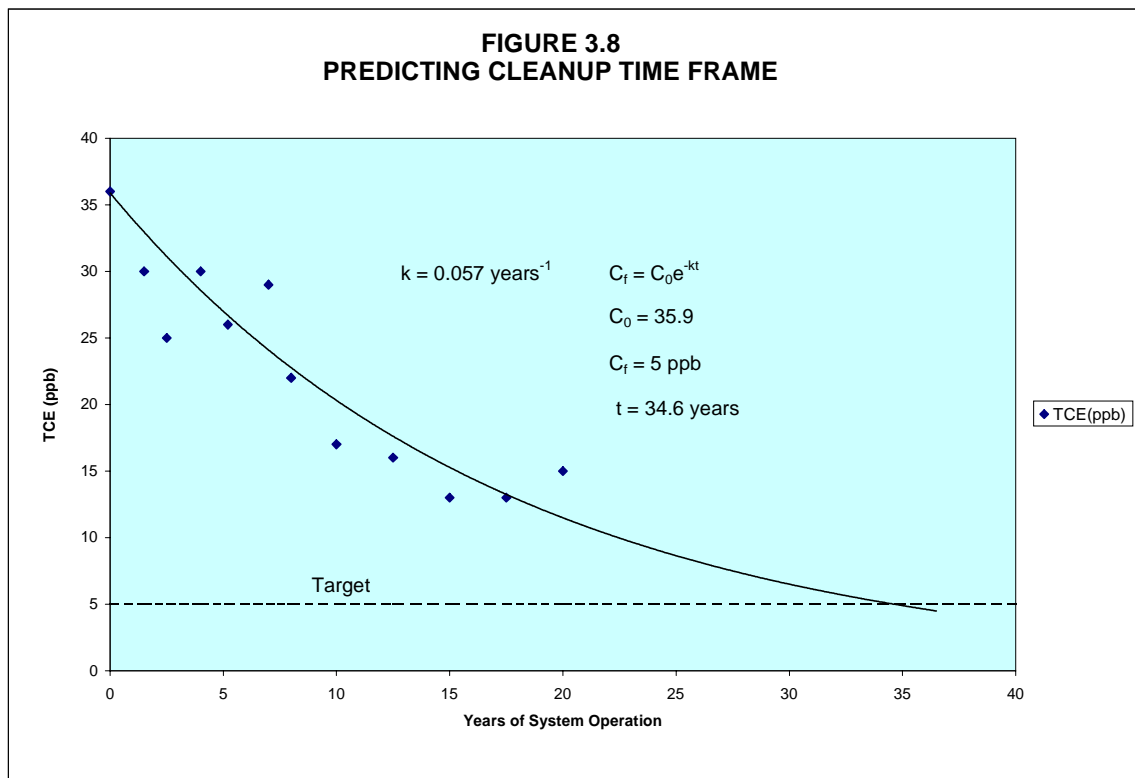
The same types of observations can be made for SVE systems. Soil gas concentrations in VMPs and extraction vent wells can be plotted against time. Consistent rebounding of soil gas concentrations in source area VMPs can indicate that saturation levels of fuel or solvent are trapped within the soil matrix.

3.5.8 Effectiveness Evaluations for Specific Technologies

Appendix C includes remedial system evaluation checklists developed by the US Army Corps of Engineers for the following remediation technologies and treatment subsystems:

- Remediation System General Evaluation
- Groundwater Extraction Subsurface Performance
- Extraction and Monitoring Wells
- Liquid Pumping and Piping Systems

**FIGURE 3.8
PREDICTING CLEANUP TIME FRAME**



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- Aboveground Treatment Systems
- Air Stripping
- Liquid Phase Carbon
- Chemical Feed and Storage Systems
- Filter Systems
- Metals Precipitation
- Solids Handling
- Process Instrumentation and Controls
- Treated Water Disposal
- Soil Vapor Extraction Subsurface Performance
- Vapor/Off-Gas Blower and Piping System
- Vapor Phase Carbon Treatment
- Bioventing
- *In situ* Air Sparging Subsurface Performance
- Oil/Water Separation
- Landfill Off-Gas Treatment
- Advanced Oxidation Technologies
- Environmental Monitoring

3.5.9 Summary of Effectiveness Evaluation

A Phase II RPO effectiveness evaluation generally will be required to demonstrate that a remediation system is "operating properly and successfully" before BRAC property can be approved for

transfer and as a part of the five-year ROD reviews and RCRA permit reapplications. The desired outcome of every effectiveness evaluation is a professional judgement to either continue operating and optimizing an existing system, or to replace that system with a more effective technology or remediation approach. In some cases, the removal of a NAPL source will be impossible, and a new regulatory approach such as a TI waiver (see Section 4.2.5) will be required. Section 3.6 describes methods for optimizing existing systems to improve effectiveness and reduce the time frame and cost of remediation.

3.6 SYSTEM OPTIMIZATION

Once a remediation approach has been evaluated and determined to be capable of achieving cleanup goals in an acceptable time frame, the RPO evaluation should seek to identify O&M inefficiencies that can be corrected through optimization. This includes a wide variety of system improvements that reduce cleanup time or costs, and modifications that can enhance the overall effectiveness of the remediation effort.

The goal of system optimization should be to achieve maximize protectiveness and risk reduction for each dollar spent on site remediation.

Optimization is an ongoing process, and many simple optimizations can and should be completed as an outcome of annual Phase I RPO evaluations. System improvements such as balancing extraction rates to improve mass removal from several extraction wells can normally be completed by the DoD facility without regulatory approval. More significant changes such as the addition or deletion of extraction wells or changes in monitoring frequency or location will often require regulatory approval, but can still be implemented as the outcome of an annual Phase I evaluation.

The Phase II RPO evaluation will include a more rigorous remedial system optimization study. The following sections present basic optimization checklists that can be used during Phase I and Phase II remedial systems optimizations. In addition to these checklists, several references provide more detailed information on individual technology optimization.

3.6.1 Source-Reduction Optimization

Remedial system optimization should begin by evaluating current efforts to reduce the source of contamination. This focus is important because contaminants (and risk) are often concentrated in the source area. More efficient source removal will often translate into

significant time reductions for extraction systems or natural attenuation monitoring.

3.6.1.1 Soil Vapor Extraction Optimization

AFCEE has prepared a document entitled “Guidance on Soil Vapor Extraction Optimization” (AFCEE, 2001) to assist site managers and RPO evaluators in assessing SVE systems. The following is a summary of the key optimization steps for SVE:

1. Has the contaminated soil volume been well-defined, and the conceptual site model validated by adequate geologic and contaminant characterization? Unfortunately, many SVE systems have been installed without the degree of subsurface characterization that is required to determine how soil heterogeneity will impact contaminant recovery. A better understanding of site geology and contaminant distribution will help to optimize extraction well screen placement for maximum recovery. If this level of characterization is lacking, new direct-push probes are available to delineate vertical contamination and soil permeability variations.
2. Based on vacuum data and soil gas chemistry changes in VMPs, is the entire contaminated soil volume

contained within the vacuum influence of the SVE system and is air flow adequate to exchange several pore volumes of soil gas each day? This can only be determined if VMPs are liberally positioned in the contaminated soil volume and are screened over discrete intervals (1 to 5 feet) within each geologic stratum where contamination is found. The performance of an SVE system cannot be optimized without adequate data from properly located VMPs. The next step in optimization may require the installation of an adequate number of VMPs screened at appropriate intervals (Figure 3.9).

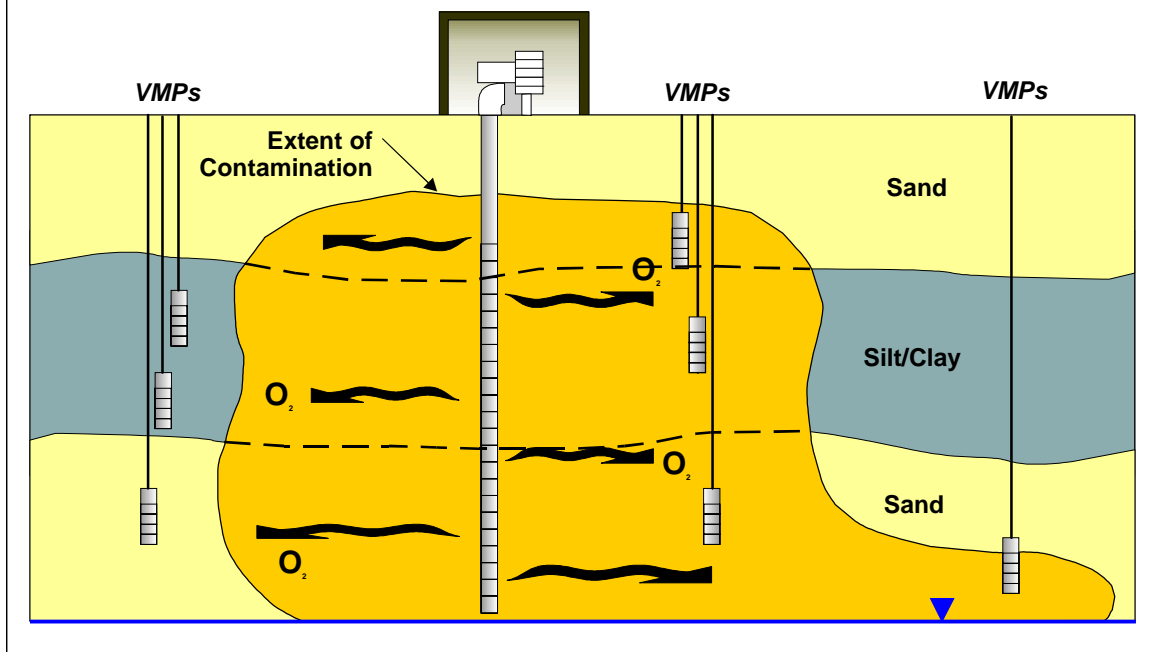
3. Collect soil gas samples and flow-rate data from each extraction well during SVE operation to determine the relative mass removal for each well. These data generally will show that some wells are significantly less efficient at removing contaminant mass. Based on these data, simple flow adjustments can be made to decrease flow from unproductive wells and increase flow from more contaminated areas of the site. The aboveground vapor treatment system should be evaluated to determine if it is still the most economical technology for the optimized flow rate and VOC vapor concentrations. Often as

concentrations decrease, the vapor treatment technology becomes less efficient and other technologies should be evaluated. The AFCEE Toolbox contains performance and costs summaries for several vapor treatment technologies that operate most efficiently at different mass loading rates. For additional information on SVE optimization, consult the *AFCEE Guidance on SVE Optimization* and other references in Appendix A.

4. Complete equilibrium tests. As discussed in Section 3.4, turning off the entire extraction system for 3 to 6

weeks will allow soil vapor concentrations to equilibrate with contaminant residuals in the soil. The site-specific equilibration period can best be estimated by using a handheld, total VOC analyzer to determine when concentrations of soil gas VOCs have "leveled off" at individual VMPs. Sampling of extraction wells and VMPs after this period of equilibration will reveal the progress of remediation, where any "hot spots" remain, and where additional air extraction should be focused. Equilibrium tests can also provide important design information on diffusion

**FIGURE 3.9
PROPER VMP PLACEMENT**



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limited zones where additional air flow will do little to improve VOC removal rates.

5. If required, complete vertical profile testing on each extraction well to determine how flow rates and contaminant recovery rates vary with depth. This specialized testing can provide additional insights into the air permeability of various layers and where the greatest mass of recoverable contamination resides in the subsurface. Down-well devices are now available to conduct these specialized tests. Based on test results, the RPO evaluation team can recommend "packing off" unproductive screened intervals or installation of new, more productive extraction wells.

3.6.1.2 Bioventing Optimization

Two criteria define a successful bioventing system: an active population of hydrocarbon-degrading microbes, and an adequate oxygen supply to the entire contaminated soil volume. Less than 3 percent of the 150 hydrocarbon sites tested during the AFCEE bioventing initiative lacked an adequate microbial population to make bioventing successful. Natural microbial processes will rarely require optimization (AFCEE, 1996). Bioventing optimization gener-

ally focuses on fulfilling the second criterion oxygen supply.

1. The first step in optimizing a bioventing system is to ensure that soil gas throughout the contaminated soil volume contains at least 5 percent oxygen. As with SVE optimization, proper placement of VMPs is critical to this optimization step. In multiple-well bioventing systems, the flow to each well can be adjusted to increase flow in areas of depleted soil gas oxygen. In some cases, a blower which will generate less flow but higher pressure is required to distribute air in less permeable soils.
2. A second step in bioventing optimization is to ensure that excessive air flow is not being applied to the air injection wells. Most bioventing systems deliver significantly more air than is required to meet the biological oxygen demand. Gradually reduce the overall air injection rate until oxygen concentrations stabilize between 5 and 15 percent in all VMPs. In some cases this optimization step will lead to replacement of the existing blower with a smaller, more energy efficient model.
3. *In situ* respiration testing can be used to further optimize the bioventing system. Because respiration tests

measure the rate of biological degradation, they can be used to identify soil volumes where microbes have significantly removed the hydrocarbon supply. Sites or areas with low respiration rates and low levels of equilibrium vapors could be candidates for direct soil sampling to determine if source area cleanup goals have been achieved. For additional information on bioventing optimization, consult the *AFCEE Bioventing Principles and Practices Manual*.

3.6.1.3 Free Product Recovery Optimization

In evaluating free product recovery, it is important to remember that the fraction of recoverable liquid contamination at most sites is small (i.e., rarely more than 33 percent of the total LNAPL and usually much less). If the initial TPH concentration in the smear zone was 60,000 mg/kg, the concentration could still be over 40,000 mg/kg after a very successful free product recovery program. The benefits of attempting free product recovery are often political or "aesthetic". Rarely do these attempts result in a measurable reduction in risk.

In light of this reality, the cost of satisfying political or aesthetic requirements should be minimized by first conducting simple "baildown" tests and in-

stalling passive skimming systems whenever possible. Only after careful pilot testing should any product recovery technology requiring pumping or expensive aboveground treatment be recommended for installation (or continued operation). The technologies available for LNAPL recovery can be grouped into three categories:

- **Passive skimming**, where only product, and minimal groundwater is extracted and no gradient is induced;
- **Groundwater depression**, where both product and groundwater are pumped, a cone of depression is produced resulting in a gravity gradient driving product flow; and
- **Dual-phase recovery** (or bioslurping), where product, groundwater, and soil gas are extracted, and a vacuum is used to enhance product flow.

Passive recovery impacts only the continuous free phase in the smear zone. Groundwater depression relies on gravity flow and requires a pump-and-treat system to create the gravity flow that recovers mobile LNAPL from the smear zone. Dual-phase recovery has a similar impact below the water table as groundwater depression, but also extracts soil gas from the vadose zone, resulting in some biodegradation (hence the term "bios-

lurping") and some volatilization. The dual-phase extraction system also may induce additional flow of LNAPL from the capillary fringe that neither skimming nor groundwater depression will effect. The drawback of groundwater depression and dual-phase systems is the high cost of treating extracted groundwater and vapors.

Determination of recoverable product at any given site is more art than science. The past standard practice of estimating product thickness in wells and trying to extrapolate a recoverable product volume has resulted in large investments in free product recovery systems that have failed to recover even 10 percent of the estimated product volume. Based on this experience, AFCEE recommends a series of simple baildown tests, limited pump down tests, and vacuum enhanced recovery tests to determine the likelihood of successful free product removal. These improved methods for pilot testing free product recovery systems are described in the *AFCEE Engineering Evaluation and Cost Analysis for the Bioslurping Initiative*, March 1997.

Alternative Approach- An alternative approach to attempted free product removal is natural weathering. Natural weathering preferentially removes benzene, which is the most toxic compound

known to exist in most LNAPLs. A recent study of jet-fuel weathering determined that benzene was naturally removed from free product and followed a first-order decay rate (AFCEE, 1999). A strong argument against free product removal is possible if a combination of natural LNAPL weathering and plume stability can be demonstrated at fuel-contaminated sites.

3.6.1.4 DNAPL Removal Optimization

By far the most difficult source of contamination to address are the DNAPL sources frequently associated with chlorinated solvent spills. To date, there is no technology that has proven reliable in reducing DNAPL sources once they have migrated below the water table. Emerging technologies such as steam injection, surfactant washing, and resistive heating have all had site-specific success at reducing DNAPL mass. The most reliable method of DNAPL reduction is excavation, and excavation will only be successful in shallow soils that do not extend too far into the saturated zone. SVE can be used to reduce DNAPL mass in sandy, unsaturated soils, but will have minimal impact if DNAPL has fully penetrated clay and silt layers.

In light of these limitations, DNAPL reduction can best be optimized through

detailed site characterization. At a small site, it may be possible to complete a tight grid of soil borings or probe pushes in the unsaturated soil near the point of release. This could provide some guidance for future excavations or SVE well locations. Partitioning tracer tests can also be used to locate DNAPL once the source area has been identified.

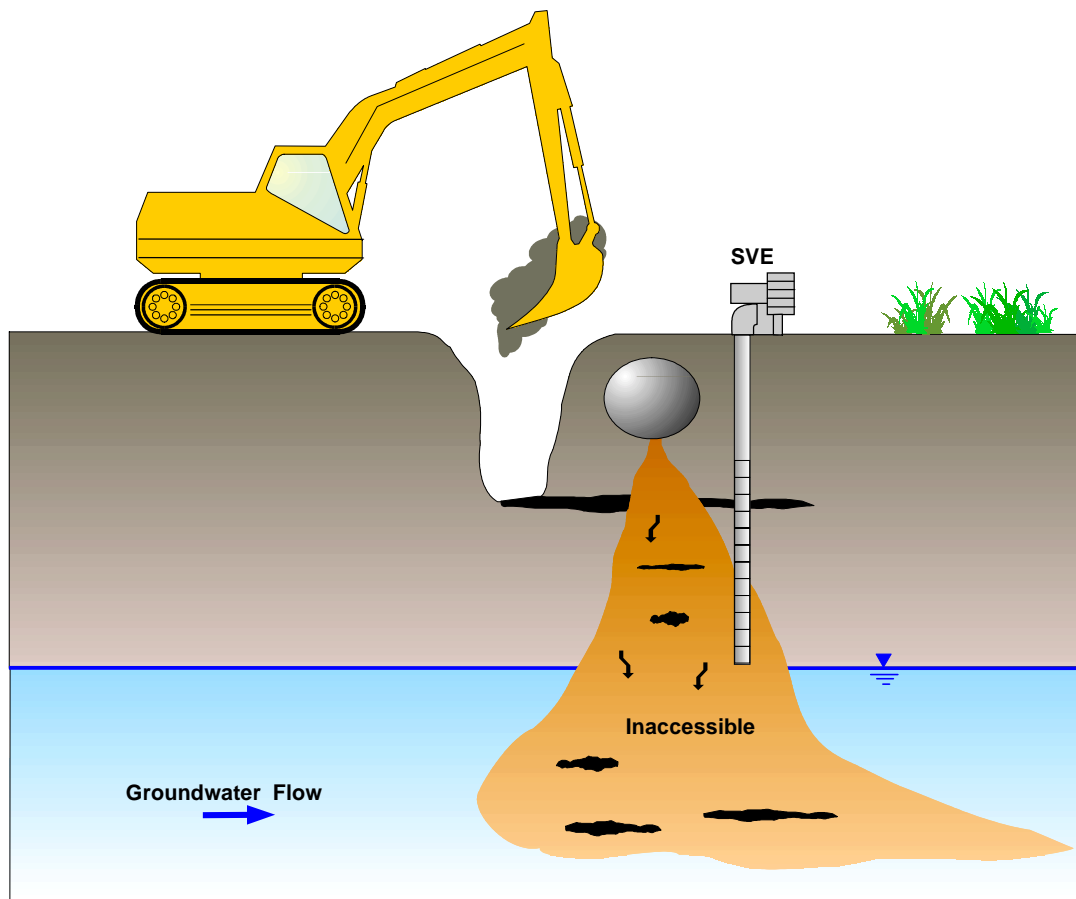
The RPO team should evaluate emerging technologies to determine if a pilot test of a DNAPL reduction technology is warranted.

If after reviewing the latest DNAPL reduction technologies, the RPO team determines that no DNAPL removal method will be effective on the site, AFCEE recommends that revised cleanup goals be evaluated for the site. Regulatory options such as TI waivers were created for DNAPL sites. Under a TI waiver, the remediation goals are revised to contain the source rather than to remediate it. EPA's *Guidance for Evaluating the Technical Impracticability of Groundwater Restoration* provides additional information on the site data that must be presented to obtain a TI Waiver from EPA. Much of these site data will be collected during the RPO effectiveness evaluation described in Section 3.

3.6.2 Groundwater Extraction System Optimization

If groundwater extraction is determined to be a necessary component of a particular remediation system, the time required for groundwater remediation using extraction techniques generally dictates the overall time frame for site remediation and represents most of the long-term operating costs. When properly optimized, changes to a groundwater extraction system can yield significant savings without sacrificing protectiveness. Pumping system optimization requires a clear understanding of subsurface conditions, a recognition of the physical limitations of diffusion-limited contaminant transport, and a clear definition of the pumping objective. There are two primary objectives for pumping: plume containment and mass removal. Plume containment systems are intended to isolate the contaminant and prevent migration. Mass removal extraction systems are intended to maximize removal of dissolved chemical mass, thereby reducing contamination throughout the plume to an acceptable cleanup level. The following sections describe conditions associated with each objective, and a generalized optimization procedure that can be applied to either objective.

**FIGURE 3.10
DNAPL REMOVAL LIMITATIONS**



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Plume Containment Optimization

The purpose of a groundwater extraction system (installed to contain a plume) is to maintain hydraulic control of groundwater so that dissolved contaminants are not transported beyond a compliance boundary. Containment of groundwater using extraction technologies ("pump-and-treat") may be a preferred remedial option in cases when a DNAPL phase is suspected to be present,

or when a plume is moving offsite. In many cases, containment pumping may be cost effective as compared with other containment options (e.g. deep slurry walls or reactive walls). Because groundwater containment systems need only contain a plume, it is necessary to extract groundwater at a rate only slightly greater than the rate at which groundwater is moving naturally through the plume volume. Groundwater extraction rates frequently incorporate large

safety factors that, based on the operational history of the system, may not be justified. In some cases, the groundwater extraction rates are the maximum the formation and/or wells can achieve, regardless of what is required for containment. These, and similar situations offer opportunities for optimizing the plume containment system.

Mass-Removal Optimization

Pump-and-treat systems designed for removal of contaminant mass are intended to extract groundwater containing dissolved contaminants from the subsurface and deliver the water to the surface for treatment, while maximizing the rate of contaminant removal. This typically requires maximizing mass removal rates while minimizing the volume of groundwater requiring treatment (locating the extraction well(s) in areas where contaminant concentrations are highest). However, since this process is mass-transfer limited; a number of factors can adversely affect system performance, and groundwater extraction systems intended for mass removal have not typically been successfully applied as stand-alone remediation systems. For example, the presence of DNAPLs can render a mass-removal system ineffective, because the rate of contaminant removal is limited by the rate of chemical dissolution from the DNAPL phase. Further-

more, in older plumes, the soluble contaminants have diffused into dead-end pores, low-permeability zones and even the aquifer matrix. In these cases contaminant removal is limited by diffusion rates.

Optimization Procedures for Groundwater Extraction Systems

Although the objectives of groundwater extraction systems may differ, depending on site-specific conditions or requirements, the general procedures for optimizing systems designed for plume containment, and systems designed for maximizing mass removal, are similar, and are described in the following sections. Where differences exist, these are noted in the discussion.

1. Has the extent of the dissolved-phase plume been adequately defined, and a conceptual site model constructed and validated using geologic, hydrologic, and chemical data adequate for site characterization? A better understanding of site hydrogeology, and lateral and vertical distribution of contaminants, will assist in optimizing the locations of extraction wells, and in optimizing the placement of the extraction interval(s) (well screens) of individual wells. If this level of characterization is not available, downhole flowmeters, di-

rect-push probes and discrete sampling can often be used to collect stratigraphic and/or water-level information and fill in data gaps regarding subsurface conditions or contaminant distribution.

2. Are source-control measures appropriate or necessary? A typical groundwater containment system extracts groundwater from the down-gradient edge of a plume, preventing further migration of contaminants. By contrast, a system designed for removal of contaminant mass will focus extraction efforts on those areas of the plume where contaminant concentrations are highest. However, without removal or reduction of the contaminant source, the distribution and concentrations of contaminants in the plume may not change appreciably through time; and therefore the rates of mass removal will eventually become asymptotic. In this case, addition of a source-control well, or implementation of other source removal or control measures, can reduce the volume of water pumped in downgradient areas and assist system optimization. Other control measures to be considered may include *in-situ* chemical destruction (e.g., injection of carbon sources to enhance reductive dechlorination),

or construction of *in-situ* barriers or treatment walls.

3. Has the potential for natural attenuation been evaluated? Natural attenuation should be incorporated into all fuel-related plume remediations and considered for chlorinated solvents. If the site-specific occurrence of natural attenuation can be demonstrated, other source-control or mass removal measures may not be necessary, and natural-attenuation mechanisms, in combination with plume containment measures, may be sufficient to prevent further chemical migration while removing chemical mass from the subsurface. Both AFCEE and the EPA have produced technical protocols describing how to document and incorporated natural attenuation into plume remediation. Appendix A provides full references for these protocols.
4. Have the design and extraction rates of individual wells in the extraction system been optimized? Based on the objectives of a particular extraction system, identification of the appropriate completion intervals for individual extraction wells can greatly enhance the effectiveness of the extraction system. Changes in well design, construction techniques, or well

materials can result in improved extraction efficiencies of individual wells. For additional information on improving well design, refer to *Groundwater and Wells* (Driscoll, 1986) or *Handbook of Ground Water Development* (Roscoe-Moss, 1990).

5. Based on drawdown and chemical data from individual monitoring wells (not data from extraction wells, which can be misleading), is the entire volume of the plume contained by the groundwater extraction system? If mass removal is the primary objective of the system, are extraction wells located in areas having historically elevated concentrations of contaminants? These concerns can only be evaluated if groundwater monitoring wells are located appropriately throughout, and down-gradient of the plume, and in the vicinity of extraction wells. The performance of a groundwater extraction system cannot be evaluated without an adequate number of appropriately-located monitoring wells. Therefore, prior to commencing optimization of the extraction system, (e.g., the wellfield), the groundwater monitoring network should be evaluated and optimized. Optimization of monitoring systems is more fully discussed in Section 3.6.5.
6. If mass removal is the primary objective of the extraction system, collect groundwater samples and extraction-rate information from each extraction well (during operation) to evaluate the relative mass removal from each point (extraction well, wellpoint, trench). These data will generally demonstrate that some wells are significantly less productive at removing contaminant mass. These data can then be used in conjunction with Step 5 (above), to identify simple adjustments that can be made to decrease extraction rates at unproductive wells, and increase extraction rates within the more contaminated areas of the plume.
7. If mass removal is the primary objective of the extraction system, is the contaminant removal rate limited by either chemical solubility or diffusion? If so, an extraction system designed to achieve contaminant mass removal may be pumping at a much higher rate than is necessary. These systems can be optimized by reducing groundwater extraction rates to better match the chemical dissolution/diffusion rates, while still preventing plume migration. Cycling all or a part of the system (i.e., systematically turning pumps on and shutting them down) can also be used to

reduce extraction rates to match dissolution/diffusion rates.

8. Complete equilibrium tests. If possible, turn off the entire extraction system for a period of three months to allow the concentrations of dissolved contaminants to equilibrate with contaminant residuals in the soil. Longer equilibrium times will be required for low-permeability and more heterogeneous soils. Sampling of extraction wells and monitoring wells after a period of equilibration, and observing concentration "rebounds" (if any) will allow the true progress of remediation to be evaluated, enable the identification of remaining "hot spots", and assist in identifying stratigraphic intervals or areas in the plume where extraction should be focused.
9. If necessary, complete vertical profile testing on each extraction well to evaluate how extraction rates and contaminant recovery rates vary with depth or particular hydrostratigraphic intervals. Borehole flowmeters and discrete sampling devices, such as diffusion samplers, can be used to develop flow and contaminant profiles for each extraction and monitoring well. This will provide additional information regarding the hy-

draulic conductivity of particular intervals, and enable identification of intervals containing the greatest mass of recoverable contaminants. Based on test results, the RPO evaluation team may recommend "packing off" unproductive intervals in particular extraction wells, or installation of new extraction wells, completed in more-productive and contaminated intervals.

10. Are individual wells in the extraction system optimally located to control plume migration, or are individual extraction wells optimally located to maximize mass removal, and is the cumulative pumping rate of the entire system the minimum necessary to achieve such control (or removal)? These questions are best addressed using drawdown calculations and/or simulation techniques. Using site-specific hydraulic, hydrologic, and groundwater monitoring information, the radius of influence and extent of the capture zone of individual extraction wells can be estimated. Groundwater capture zones for individual wells can then be projected onto a map of the plume and drawdowns superimposed so that the degree of plume containment can be estimated. This exercise should be completed using several different ex-

traction rates for each well, within the range of extraction rates that can physically be achieved, depending on the aquifer characteristics at particular locations. Well locations and extraction rates can then be adjusted to improve the effectiveness of containment or removal, and reduce groundwater extraction rates. Extraction system optimization can subsequently be refined, using analytical or semi-analytical techniques (e.g., Blandford and Huyakorn, 1990), or numerical models of groundwater flow (such as MODMAN), combined with trial-and-error or numerical optimization methods.

11. The aboveground water treatment system should be evaluated to determine whether it remains the most economical technology for the optimized extraction rates and contaminant concentrations. Often, as influent concentrations decrease, a particular treatment technology may become comparatively less efficient (air stripping may eventually be replaced with carbon treatment). Techniques for optimizing aboveground treatment systems are discussed in the following section.

3.6.3 Aboveground Treatment Optimization

Although a wide variety of aboveground systems exist for groundwater and vapor treatment, these systems have common objectives and operating principles. The optimization of aboveground treatment systems can be achieved by following the general steps outlined in this section. The equipment manufacturer should be consulted for additional, system-specific optimization recommendations. Appendix C includes information for obtaining RPO checklists for specific aboveground treatment systems.

1. Review influent and effluent data to determine if each component of the treatment system is achieving both its design removal efficiency and the regulatory discharge limits. Note any efficiency problems and call the equipment manufacturer to discuss possible maintenance or aging problems that could lead to inefficient operation. Correct these problems and monitor to ensure that efficiency improves.
2. Many systems are over-monitored and under maintained. If the system has a history of frequent shutdowns, it may not be receiving adequate preventative maintenance. Make sure that the labor hours being expended

at the site are productive, and that required system maintenance is not being overlooked. An audit of O&M hours, and what activities are charged to O&M, is an essential Phase I activity.

3. Many treatment systems are over designed for current site conditions. Once the influent flow rate and/or contaminant concentrations begin to decrease, the contaminant mass loading to these systems is much less than design capacity. While total replacement of installed systems may not be economical, many of the energy-consuming components such as transfer pumps and blowers can be replaced with smaller, more efficient motors without sacrificing treatment efficiency.
4. In some cases, optimization will require a more complete cost-benefit analysis that compares continued operation of existing equipment to replacement with more efficient, state-of-the-art equipment. This is particularly true of vapor treatment equipment that uses thermal destruction to remove VOCs. These units are very inefficient when operated below design mass loadings and consume large quantities of auxiliary fuel such as natural gas or propane.

Replacement of these units will often generate fuel savings that rapidly pay back the cost of the new equipment.

5. Significant savings in remedial systems O&M will be realized through labor reductions. Improved remote control systems and modern telemetry/computer interfaces allow many simple treatment systems to operate for weeks without on-site labor. For large treatment systems with decades of future operations, these system enhancements can translate into significant savings. A systems controls expert should be consulted to determine what remote monitoring and control opportunities exist. There should be an appropriate balance between automation and human oversight of the system.

3.6.4 Monitoring Optimization

Remedial action monitoring will have several goals that should be clearly stated in the project DQOs. These goals typically include:

- Assessment of remediation progress;
- Operational performance of remedial system;
- Confirmation of remediation effectiveness; and

-
-
- Final confirmation of cleanup goals.

Long-term monitoring of soil, groundwater, and aboveground treatment systems represents a significant percentage of the total O&M cost for the current and future DoD remediation program. Considerable emphasis has been given to reducing the overall cost of monitoring without sacrificing the reliability of monitoring programs. Several helpful references have been developed to assist site environmental managers and consultants with the optimization of site monitoring and analysis procedures. The primary reference for this topic is the *AFCEE Long-Term Monitoring Optimization Guide*, (Appendix D). Statistical methods have also been developed to assist site managers in monitoring optimization.

3.6.4.1 Phase I Monitoring Optimization

The following Phase I monitoring optimization checklist has been summarized from the reference listed above.

1. Review the existing site monitoring program and determine if all of the monitoring wells/VMPs are useful for tracking remediation progress or are required by regulatory decision documents. Identify redundant wells for elimination and abandonment.

When required, support these decisions with a statistical spatial analysis. Monitoring well elimination typically will require regulatory approval.

2. Is the sampling frequency appropriate based on the rate of remediation progress? At many sites groundwater is monitored quarterly or semiannually based on requirements that were established during the initial site investigation. Once seasonal variations have been established, annual monitoring of subsurface conditions (during the same month each year) typically is sufficient to track remediation progress. When required, support these decisions with statistical temporal analysis. Aboveground treatment systems may require more frequent monitoring to ensure desired system effectiveness and that discharge limits are being achieved.
3. Is the sampling and analytical protocol appropriate for monitoring remediation progress? Sampling and analytical protocols for remediation system monitoring are not as rigorous as those required for the initial site investigation. Check to ensure that the

analytical methods can detect contaminants of concern at the desired quantitation limits and at levels that are appropriate for the use of the data. For example, only the treatment system effluent and point-of-compliance monitoring wells may require low detection limits and the strict quality assurance/quality control. The new *AFCEE Remedial Process Optimization Field Procedures and Quality Assurance Protocol* (Appendix E) provides guidance on appropriate data quality objectives (DQOs) for different remediation scenarios.

3.6.4.2 Phase II Monitoring Optimization Methods

The Phase II monitoring optimization could include the use of several advanced characterization and statistical analysis tools. The Monitoring (MAROS) is a user-friendly software package that has been developed by AFCEE to simplify the analysis of monitoring networks, to analyze contaminant trends, and to optimize site monitoring programs. Appendix G provides additional details on MAROS and other monitoring optimization programs. This software package can be applied both to natural attenuation situations and to active pumping systems and normally re-

quires monitoring data from four sampling events.

Temporal Trend Analysis - Temporal data (chemical concentrations measured at different points in time) can be examined visually, or with statistical tests, to evaluate plume stability. If removal of chemical mass is occurring in the subsurface as a consequence of attenuation processes or operation of the remediation system, mass removal will be apparent as a decrease in chemical concentrations through time at a particular sampling location, as a decrease in chemical concentrations with increasing distance from chemical source areas, or as a change in the suite of chemicals through time or with increasing migration distance.

Temporal concentration data can be evaluated by plotting contaminant concentrations through time for individual monitoring wells, or by plotting contaminant concentrations versus down-gradient distance from the contaminant source for several wells along the groundwater flowpath, over several monitoring events. The possibility of arriving at incorrect conclusions regarding plume stability on the basis of visual examination of temporal concentration data can be reduced by examining temporal trends in chemical concentrations

using various statistical procedures, including regression analyses and the Mann-Kendall test for trends.

The Mann-Kendall non-parametric test (Gilbert, 1987) included in the MAROS software is well suited for application to the evaluation of environmental data because the sample size can be small (as few as four data points), no assumptions are made regarding the underlying statistical distribution of the data, and the test can be adapted to account for seasonal variations in the data. The Mann-Kendall test statistic can be calculated at a specified level of confidence, to evaluate whether a temporal trend is present in contaminant concentrations detected through time in samples from an individual well. If a trend is determined to be present, a non-parametric slope of the trend line (change per unit time) can also be estimated using the test procedure. A negative slope (indicating decreasing contaminant concentrations through time) or a positive slope (increasing concentrations through time) provides statistical confirmation of temporal trends that may have been identified visually.

Specific guidance has been developed by AFCEE to assist in establishing monitoring networks for natural attenuation sites and evaluating the progress of

natural attenuation processes (Wiedemeier and Haas, 1999).

Spatial Trend Analysis - Spatial statistical techniques can also be applied to the design and evaluation of monitoring programs to assess the quality of information generated during monitoring, and to optimize monitoring networks. The Theory of Regionalized Variables (Clark, 1987; Rock 1988; American Society of Civil Engineers [ASCE], 1990a and 1990b) evaluates data that are dependent on location, and are continuous in space, but which vary in a manner too complex for simple mathematical description. The theory of regionalized variables states that the differences in values of a spatial variable depends only on the distances between sample locations, and the relative orientations of sample locations -- that is, the values of a variable (e.g., concentrations of TCE) measured at two locations that are spatially "close together" will be more similar than values of that variable measured at two locations that are "far apart". If the known sample values are used, the value of the variable (e.g., chemical concentrations) at any point within the sampled region can be estimated, in the process known as «kriging» (Clark, 1987; ASCE, 1990a and 1990b). An additional advantage of kriging is that the standard deviations ("errors") associ-

ated with the values estimated at each point in the spatial domain can also be calculated during the kriging process. Areas containing estimated concentration values having elevated standard deviations associated with them represent locations where additional monitoring data could be collected to reduce uncertainties regarding the extent of VOCs in the subsurface. This observation implies that the monitoring program could be “optimized” by using available information to identify those areas having the greatest associated uncertainty. Conversely, sampling points can be successively eliminated from simulations, and the standard deviations examined, to evaluate if significant loss of information (represented by increases in standard deviations) occurs as the number of sampling points is reduced. Repeated application of these geostatistical estimating techniques can then be used to generate a sampling program that would provide an acceptable level of uncertainty regarding chemical distribution across the area to be monitored, with the minimum possible number of samples collected.

Discrete-level Monitoring Devices – Advanced monitoring technologies such as borehole flowmeters, and discrete-level monitoring devices, such as diffusion samplers, are useful for determining the vertical intervals of groundwater

flow and of maximum and minimum contamination. This information can be used to redesign extraction wells for optimum plume containment or mass removal and to place monitoring wells at the appropriate interval(s) to monitor remediation progress. Similar advancements are available for SVE monitoring optimization. The Geoprobe Membrane Interface Probe System® (MIPS) and the Praxis PneuLog® device are capable of providing a continuous vertical profile of soil permeability (or soil type) and VOC concentrations. This information greatly improves our understanding of subsurface air flow and diffusion-limited VOC removal and is critical data for SVE optimization in layered soils.

3.6.4.3 Monitoring for Site Closure

The Phase II RPO evaluation should determine, with input from responsible regulators, the statistical method to be used to demonstrate that site cleanup goals have been attained. The monitoring program must be designed to provide the data set that will be required to determine if soil or groundwater has been remediated to cleanup standards.

In many cases, the 95 percent upper confidence limit (UCL) on the mean concentration can be compared to cleanup goals in lieu of maximum con-

centrations detected on the site. A clear understanding of statistical sampling and data analysis methods will help to determine when active remediation can be terminated at a site. EPA's (1996) *Soil Screening Guidance Document* provides a variety of statistical approaches for sampling soils and comparing results to generic, risk-based soil screening levels (SSLs). Statistical methods for evaluating groundwater remediation are described in the EPA (1992) publication, *Methods for Evaluating the Attainment of cleanup standards, Volume 2: Groundwater*. This publication describes how monitoring well data should be collected to evaluate progress toward site cleanup goals.

3.6.4.4 Automated Monitoring

Many aboveground treatment systems are excellent candidates for computerized automations. Sensor technologies for flow and general contaminant indicators, such as total VOCs, are already available. Sensors for specific chemicals are still in the testing stage but these sensors may someday replace the need for conventional sampling and analytical methods. Site managers should encourage their consultants to continually review and test new hardware and software developments in monitoring optimization.

3.7 IDENTIFYING AND ESTIMATING COST SAVINGS

3.7.1 Identifying Cost-Reduction Opportunities

While cost saving is not the only objective of RPO evaluations, cost savings are the natural outcome of more efficiently operated and maintained systems. Recall that remedial system optimization should seek to maximize the protectiveness and risk-reduction of each dollar spent. To accomplish this, the RPO evaluators should:

- Review the major contributors to O&M costs and determine if each expenditure is adding value through increased protectiveness or risk reduction.
- Determine what system improvements will reduce O&M costs or reduce the remediation time frame without sacrificing protectiveness.
- Compare the cost of implementing these improvements to the future cost savings that will be realized.
- Prepare a simple cost-benefit analysis for presentation to funding authorities.

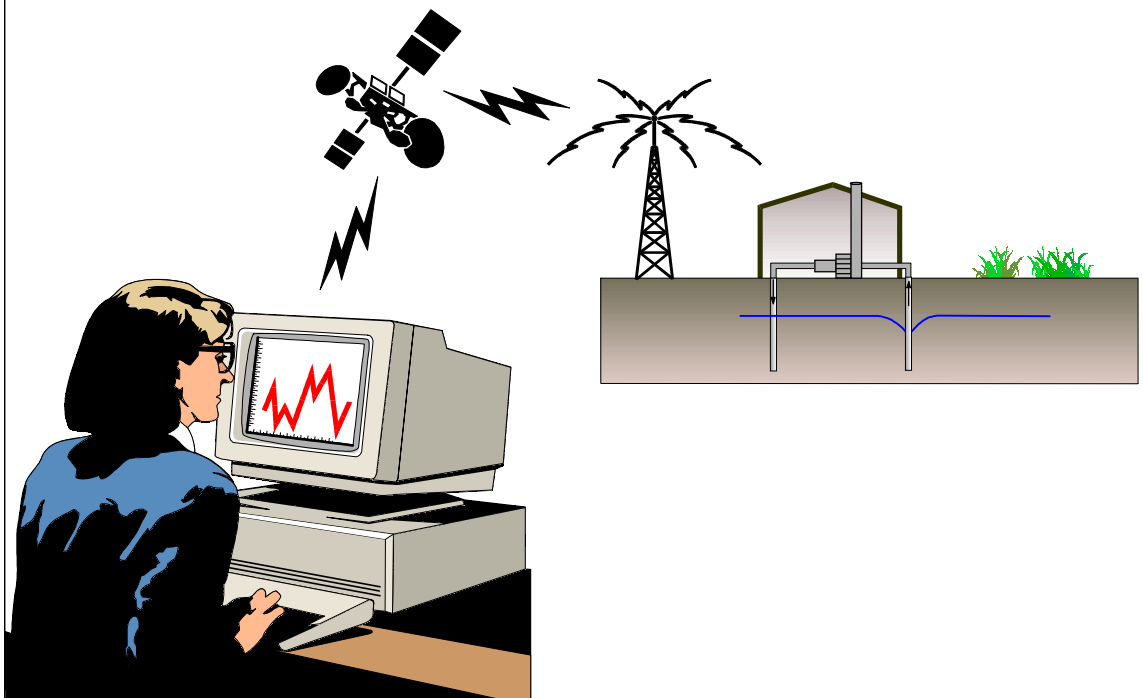
3.7.2 Calculating and Presenting Potential Savings

Figure 3.12 provides an example of a cost-benefit analysis to assist site man-

agers and other RPO evaluators in calculating and presenting the potential savings from a typical system improvement. The sample calculations assume a 5-percent annual inflation rate. A present-worth analysis is not appropriate for federal government RPO cost-benefit

evaluations because annual appropriations are for expenditure not investment. Each optimization project should be compared to other potential projects and recommended for funding based on the payback ratio or total projected savings.

**FIGURE 3.11
REMOTE CONTROL AND MONITORING**



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FIGURE 3.12 EXAMPLE COST-BENEFIT ANALYSIS

A groundwater pump-and-treat system has been operating for 3 years and is experiencing asymptotic contaminant recovery rates at all wells. Based on the drop in contaminant concentrations and relatively small equilibrium rebound in the source area, the RPO evaluation has determined that the system should achieve cleanup goals within 20 years. The existing system appears to be oversized. Several of the wells are extracting low levels of contamination and significant volumes of groundwater. Borehole flow-meter testing and discrete sampling in several extraction wells indicate that water from a relatively clean, deep sand unit is diluting the system. A simple flow optimization model indicates that by replacing the six existing wells with four new wells with optimum screened intervals, the plume could be remediated by extracting 100 gallons per minute (gpm) versus the existing 200 gpm extraction rate.

Current Annual Pumping Costs

Power for six 1-HP submersible pumps:

6HP X .746kw/HP X 1.25 efficiency factor X \$.06/kwhr X 24hrs/day X 365 days/year	=	\$2,940/yr
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Power for 5HP Air Stripper booster pump:		\$2,450/yr
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Power for 10HP Air Stripper blower:		\$4,900/yr
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Maintenance on Submersible Pumps: \$2000/pump X 6	=	\$12,000/yr
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Semiannual Monitoring of Extraction Wells: \$1000/well	=	<u>\$6,000/yr</u>
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Total Power and Pump Maintenance/Monitoring Costs:		\$28,290/yr
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Cost of 20 years of operation at 5% inflation:		\$933,570
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(Assume labor for air stripper monitoring and maintenance will be the same for 100 gpm as 200 gpm)

Optimized System Pumping Costs

Power for four -1/2HP submersible pumps:		\$980/yr
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Power for 3HP booster pump:		\$1,225/yr
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Power for 5HP blower:		\$ 2,450/yr
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Maintenance of Submersible pumps: 4 X \$2000/yr/pump	=	\$8,000/yr
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Semiannual Monitoring of Extraction Wells: 4 X \$1000/well	=	<u>\$4,000/yr</u>
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Total Power and Pump Maintenance/Monitoring Costs:		\$16,655/yr
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Cost of 20 years of operation at 5% inflation:		\$549,615
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Total 20 year cost savings of Optimized System: \$933570-549615	=	\$383,955
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Capital Cost of Optimized System

(Keep air stripping tower "shell" and replace original unit with smaller unit when original unit needs to be replace)

Four new extraction wells: 4 X \$12,000/each	=	\$48,000
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Four new submersible pumps installed: 4 X \$4000/each	=	\$16,000
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New Booster Pump:		\$5,000
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New Blower:		\$4,000
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Project Design and Management:		\$15,000
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Total Optimization Capital Cost:		\$88,000
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Cost-Benefit Analysis: A expenditure of \$88,000 today will improve system efficiency without sacrificing protectiveness and result in \$384,000 in future OM&M savings. Payback Ratio: 384/88=4.36

SECTION 4 – IMPLEMENTING PHASE II RPO RECOMMENDATIONS

Recommendations from annual Phase I performance evaluations and more detailed Phase II RPO evaluations must be properly documented and presented through the appropriate DoD and regulatory process if they are to receive the necessary attention and funding for Phase III implementation. Sections 2.3 and 2.4 provided guidance on reporting and implementing routine Phase I RPO recommendations. Many system improvements and monitoring changes recommended during Phase I annual reviews can be implemented without the need for extensive regulatory review or MAJCOM requests for new funding. This section provides guidance on how to document and implement more complex Phase II RPO recommendations.

4.1 DOCUMENTATION OF RECOMMENDATIONS

The documentation for Phase II RPO evaluations must be tailored to the specific remedial system and responsive to regulatory requirements. The Phase II RPO evaluation should be structured so that it can be used as a stand-alone document by the DoD or as a supplement to 5-year ROD reviews, RCRA permit reapplications, or OPS demon-

strations. The outline shown in Figure 4.1 is suggested to report the findings of a Phase II RPO evaluation for a pump-and-treat system. This outline should provide the necessary flexibility for a variety of applications. Phase II recommendations are generally reviewed by the site manager and then forwarded to MAJCOM or appropriate headquarters for additional review and consideration for funding of system optimizations or technology replacements.

4.2 IMPLEMENTATION OF PHASE II RECOMMENDATIONS

The coordination and approval requirements for Phase II recommendations are generally more rigorous than for Phase I recommendations. This section describes the requirements for several common Phase II evaluation scenarios:

- A remedy is ineffective or not protective;
- The opportunity exists to modify cleanup goals exists;
- Preparing for a 5-year ROD review
- Preparing a RCRA corrective action permit reapplication; or

FIGURE 4.1 EXAMPLE PHASE II RPO EVALUATION REPORT OUTLINE

1.0 Project Overview

- 1.1 Purpose and Scope
- 1.2 Site History
- 1.3 Remedial System and Monitoring Program Description

2.0 Review of Conceptual Site Model

- 2.1 Current CSM
- 2.2 Trends in Contaminant Concentrations and Movement
- 2.3 Natural Attenuation Evaluation
- 2.4 Exposure Pathways and Receptors
- 2.5 Refinement of CSM

3.0 Evaluation of Cleanup Goals

- 3.1 Review of Regulatory Decision Document
- 3.2 Remedial Action Objectives
- 3.3 New Regulatory Options
- 3.4 Evaluation of Risk-Based Goals
- 3.5 Recommended Revisions to Cleanup Goals

4.0 Evaluation of Remedial System

- 4.1 Influent Concentration and Flow Trends
- 4.2 Monitoring Well Concentration Trends
- 4.3 Equilibrium Test Results
- 4.4 Treatment System Effluent Trends vs. Discharge Limits
- 4.5 Performance Criteria/Progress Milestones
- 4.6 Performance To Date
- 4.7 Determination of Effectiveness
- 4.8 Optimization Opportunities
- 4.9 New Technology/New Approach Opportunities

5.0 Cost Evaluation

- 5.1 Summary of Annual OM&M Costs
- 5.2 Cost-Benefit Analysis of Proposed System Changes

6.0 Recommendations (as appropriate)

- 6.1 Optimization Activities
- 6.2 New Technology Opportunities
- 6.3 Revised Cleanup Goals or Approach such as TI Waiver
- 6.4 New Technical Approach such as Source Isolation/Plume Containment

7.0 Implementation Plan (as appropriate)

- 7.1 Five-Year ROD Review
- 7.2 RCRA Permit Reapplication
- 7.3 OPS Demonstration
- 7.4 Schedule for Implementation

-
-
- Preparing documentation for an OPS demonstration.
 - Requesting a Technical Impracticability (TI) waiver.

4.2.1 Ineffective/Non-Protective Remedy

If the Phase II RPO evaluation determines that the existing remedy is not effective or is not protective of human health or the environment (e.g., a plume is migrating outside of the extraction system zone of influence), CERCLA, RCRA, and state UST regulations will require the site owner to notify the responsible regulatory agency. The exact language and timing of this notification will generally be specified in the site-specific ROD, RCRA permit, or other decision document. At a minimum the notification should include a cover letter summarizing the evidence that indicates ineffective/non-protective performance. If a Phase II RPO evaluation has been performed, this document can be attached. Notification that a remedy is no longer protective may result in a notice of violation from the regulatory agency if a contingency plan for resolving the problem is not provided in a timely manner.

4.2.2 Implementation Through Five Year ROD Reviews

4.2.2.1 Review of Remedial Action Objectives

According to Section 121(c) of CERCLA, remediation systems must be evaluated at least every 5 years after completion of remedial system construction. Additional information on this review process is found in *Five-Year Reviews –Version 3, (EPA, April 1999)*. Also known as "5-Year ROD Reviews," this process requires that a review of remedial action objectives be completed for all sites where hazardous substances are expected to remain after the completion of remediation. Appendix C of the EPA Five-Year Review Guidance provides detailed requirements for evaluating existing remedial action objectives and proposing changes. New remedial action objectives can be proposed based on current site conditions and a review of ARARs or site-specific, risk-based goals.

The greatest opportunity for change will exist at sites that, though clearly in industrial areas, have RODs requiring cleanup to residential health-based cleanup goals. The EPA Brownfields initiative has revised the cleanup goals for dozens of RODs. These RODs have been rewritten to specify industrial risk-based standards rather than default resi-

dential standards. The RPO process should focus on revising cleanup goals based on industrial standards for sites that are in flightline and industrial areas. This also applies to facilities scheduled for closure when future land use can be controlled through deed restrictions.

4.2.2.2 Review of Protectiveness and Effectiveness Criteria

According to the *EPA Five-Year Review Guidance*, the primary purpose of these reviews is to determine whether or not the remedy remains protective of human health and the environment. Several factors must be evaluated to make this determination, including determining if the remedy is effective and functioning as designed, if O&M are adequate, and if there are indicators that would suggest that the system may fail to achieve remedial action objectives in the future.

Each of these factors is an important element of the Phase II RPO evaluation, and should directly support the 5-year review process. For this reason, the Phase II RPO evaluation should be completed at least 1 year in advance of the 5-year ROD review.

According to EPA guidance, there are four levels of ROD review. Level 1 is completed for sites where construction is complete and available site data are suf-

ficient to determine if the remedy is protective. Level 1a is a streamlined review that is used for sites with remedies under construction. Level 2 is used when new toxicity data prompt a recalculation of risk. Level 3 reviews are required when new site conditions or exposure assumptions are required to support a new risk assessment. RPO evaluations that promote revised cleanup goals based on site-specific risk assessments will be used to support Level 2 or Level 3 ROD reviews. RPO evaluations that do not propose revised cleanup goals will generally support Level 1 ROD reviews.

There are six primary steps in a 5-Year ROD review:

- Planning
- Document Review
- Interviews
- Site Visit
- Evaluation
- Report Preparation

With the exception of interviews, the Phase II RPO evaluation closely parallels these steps, with an emphasis on evaluating the effectiveness of the remedy in achieving the remedial action objectives established in the ROD. *Appendix E of the Five-Year Review Guidance* specifies that the 5-year ROD review report should clearly specify whether or not the remedial system is effective and func-

tioning as designed, whether or not early indicators of system failure are evident, and what optimization opportunities or new technologies may exist to improve effectiveness.

At CERCLA sites, the five-year ROD review report will function as the primary regulatory document for introducing the findings and recommendations of the RPO evaluation.

4.2.3 Implementation Through RCRA Permit Reapplications

Implementation of RPO recommendations for sites that are regulated under RCRA will normally require a RCRA permit modification. There are three levels of RCRA permit modification that are described in 40 CFR 270.42:

- Class I Modifications – Generally for minor changes to system operation, monitoring schedules, and administrative changes. Class I permit modifications are normally requested with a letter to the regulatory agency. Examples of RPO recommendations which would require Class I permit modification include extraction rate optimizations that do not negatively impact plume containment and improvements to the existing aboveground treatment systems.

- Class II Modifications – This level of modification generally requires more substantial background and supporting technical documentation. Examples of RPO recommendations which could require Class II modifications are deletion of monitoring wells, changes in point-of-compliance wells, and new aboveground treatment technologies.

- Class III Modifications – Generally require complete permit reapplications. Although the definition of what triggers a Class III modification is subject to interpretation for corrective action systems, RPO recommendations which substantially alter the remedial approach (such as replacing pump-and-treat with a barrier wall), or propose new cleanup goals (such as ACLs), will require a Class III modification.

RCRA permit reapplications are normally required every 10 years, but can be processed on a more frequent basis if changing site conditions or system ineffectiveness require significant changes to the remediation approach. The RCRA permitting process can be cumbersome and time consuming. Many state agencies charge significant fees for processing permit reapplications. Based on these constraints, the following recom-

mendations are offered for implementing RPO recommendations under RCRA:

1. Because optimization of an existing remediation system can often be approved using a simple Class I permit modification, optimization is preferred over technology change.
2. If system ineffectiveness can only be remedied through the use of a new technology or remediation approach, the cost of an immediate Class III permit reapplication must be weighed against the environmental or O&M cost of withholding recommendations until the required 10-year permit renewal.
3. If the existing system is unable to meet permit conditions, such as preventing plume migration, the DoD is required to notify the responsible regulatory agency immediately and submit an emergency permit in accordance with 40 CFR 270.61. RPO evaluations can generate the technical recommendations to support the emergency permit.
4. If the RPO evaluation recommends a major change in cleanup goals such as a TI waiver or ACL, the regulatory agency representative on the Phase II RPO team should provide guidance on how to pursue these regulatory alternatives. Under RCRA, changes in groundwater protection standards can

be proposed at any time. The permit reapplication process allows for revision of cleanup goals if a strong technical case can be made for ACLs or for a TI determination. RCRA Subpart 264.94 spells out criteria that must be satisfied to obtain ACLs. At a minimum, the DoD would have to show that the groundwater impacted by hazardous chemicals is non-potable or that natural attenuation will reduce ACLs to levels below MCLs before any exposure pathway is completed to a drinking water aquifer or surface water.

4.2.4 Supporting OPS Demonstrations

In 1992, Congress enacted the Community Environmental Response Facilitation Act (CERFA) to clarify CERCLA Section 120(h)(3) language regarding remedial actions at federal facilities that are scheduled for closure/property transfer. Specifically, CERFA states that federal property can be transferred to non-federal parties "if construction and installation of an approved remedial design has been completed and the remedy has been demonstrated to the EPA Administrator to be operating properly and successfully."

The intent of this legislation was to speed the transfer of closed military installations to local governments and de-

velopers while giving EPA Regional Administrators the responsibility for determining if the existing remedy is performing as designed and can be expected to meet final cleanup goals. This legislation applies to both NPL and non-NPL sites where final (not interim) remedial actions are underway. RCRA corrective actions that are the "sole and final response" for a site are also covered under these land-transfer guidelines (EPA, 1996).

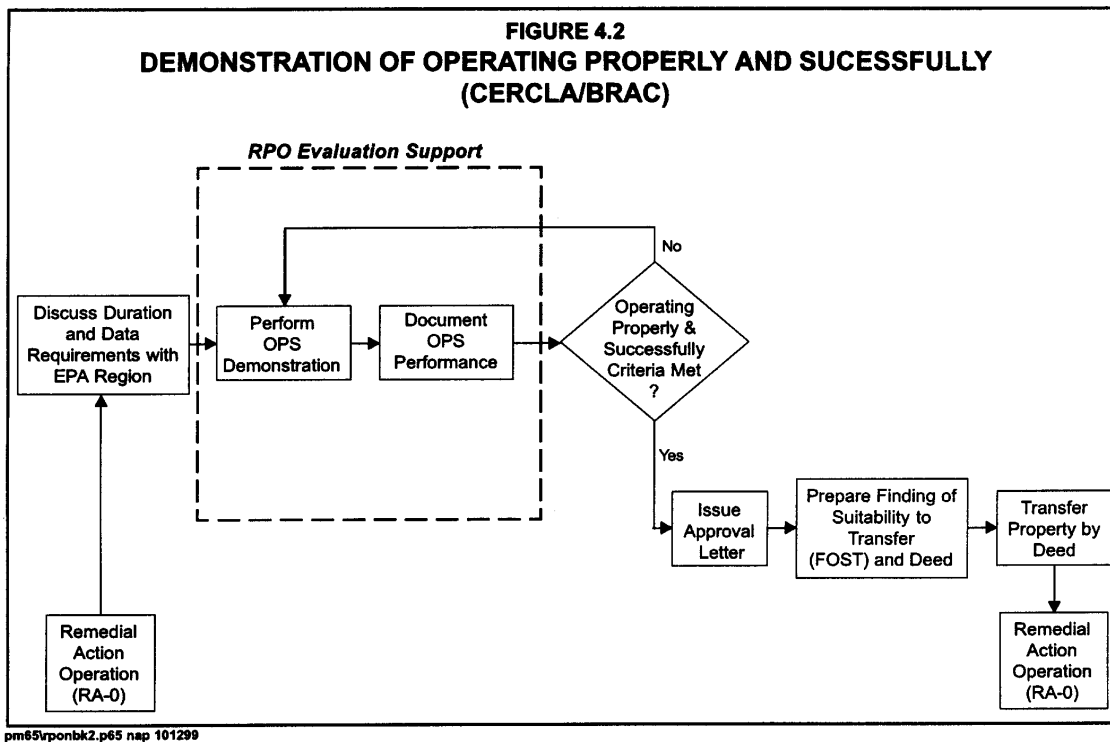
According to EPA guidance, "The phrase operating properly and successfully involves two separate concepts. A remedial action is operating 'properly' if it is operating as designed. A remedial action is operating 'successfully' if its operation will achieve the cleanup levels or performance goals delineated in the decision document. Additionally, in order to be successful, the remedy must be protective of human health and the environment....Because the EPA must make a present judgement about the future performance of a remedial action, federal agencies are expected to present sufficient evidence supporting their contention that all remedial actions necessary at the site have been taken."

The document, *The Environmental Site Closeout Process* (DoD, 1998) and *Air Force Property Transfer Guidance*:

Certification of When an Environmental Cleanup Remedy is In Place and Operating Properly and Successfully (US Air Force, 1997) provide general guidance on the OPS demonstration process and how this process fits into the overall site-transfer strategy for BRAC facilities. Figure 4.2 illustrates the site-transfer process when an OPS demonstration is required prior to issuing a Finding of Suitability to Transfer (FOST).

This handbook provides guidance on how to organize a team of experts to conduct an effectiveness evaluation and how to gather the type of evidence that EPA will require before an OPS demonstration can be approved. RPO evaluations will be most effective if they can be scheduled after a pump-and-treat system has operated for at least 2 years (6 months for SVE systems). However, appropriate data to support the OPS demonstration must be collected and assembled over the 2-year period preceding the RPO evaluation if the evaluation is to accomplish its goal of supporting the OPS demonstration.

Section 3.5 identifies the primary effectiveness criteria that should be included in an RPO evaluation if it is to successfully support an OPS demonstration. In addition to these criteria, the



EPA Guidance for Evaluation of Federal Agency Demonstrations that Remedial Actions are Operating Properly and Successfully (Interim, August 1996) provides a more detailed listing of "core criteria" that must be achieved to obtain an OPS approval. Once the Phase II RPO evaluation is completed, the effectiveness evaluation can be used as the technical basis for the OPS demonstration documentation. The following outline is recommended for incorporating RPO findings into and completing OPS documentation and is consistent with the Figure 4.1 outline:

- Identification of proposed property for transfer;
- Description of the remedial actions underway;
- Presentation of performance data that indicates that the remedies are operating as designed (RPO evaluation findings);
- Presentation of contaminant trend data that indicate that the remedy will eventually achieve cleanup standards (RPO evaluation findings);
- Identification of proposed deed restrictions or contingency plans required for monitoring the integrity of the remedial action;
- List of documents that support the OPS approval (RPO evaluation report);

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- Identification of any issues on adjacent parcels that may affect the operation of the installed remedy.

If the Phase II RPO evaluation determines that remedial actions are effective, the RPO report will provide the data and performance evaluation to directly support the OPS determination. At BRAC sites, the OPS demonstration report will function as the primary regulatory document for introducing the effectiveness findings of the RPO evaluation. However, if the RPO evaluation determines that the system is not effective or is non-protective, or recommends new regulatory approaches or technologies, these findings would normally indicate that an OPS demonstration cannot be successful until remedy effectiveness is improved. In this case, the RPO document will be used to support remedy change through the 5-year ROD review, RCRA permit reapplication, or some other process that is stipulated for remedy improvements or corrections.

4.2.5 Technical Impracticability Waivers

The USEPA has published "*Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, Sept 1993*" for assisting CERCLA and RCRA site managers in applying for TI waivers. These waivers can be granted either before remedial design, or after a

state-of the-art technology has failed to achieve cleanup objectives. The approval of a TI waiver is much more likely after source reduction technologies have been attempted and have failed to significantly reduce the source. Additional requirements for obtaining a TI waiver include:

- Specifying the cleanup standard for which the TI waiver is sought;
- Specifying the area over which the waiver will apply;
- Approval of a conceptual site model that explains why traditional cleanup goals can not be obtained (e.g., deep DNAPL source);
- An analysis of remediation progress to date (an RPO evaluation);
- Modeling to estimate timeframe and costs to attain cleanup levels using the available system; and,
- A demonstration that no other technology can attain cleanup in a "reasonable timeframe."

The USEPA guidance recommends several types of alternative remedial strategies that can be proposed in the TI waiver. Exposure control using land use restrictions and source containment with downgradient plume remediation are ex-

amples of remedial strategies that can be used to protect human health and the environment without complete restoration of the soil or groundwater. A TI decision must be recorded in the site ROD or RCRA permit/enforcement document. RPO evaluations should be completed at least one year in advance of ROD reviews or RCRA permit reapplications so that RPO findings can be incorporated into the TI waiver request.

4.2.6 Dealing With Non-Degradation Policies

Several states, including California, have established non-degradation policies which promote the goal of returning all contaminated groundwater to near pristine conditions. While this goal is often physically impossible, regulators are pressured to try to achieve these goals. Many state groundwater regulations include a "mixing zone" concept that allows contamination to remain within a designated area so long as the source is removed, exposure is controlled, and regular monitoring can demonstrate that migration outside of the designated mixing zone does not occur. This approach is most successfully applied at contaminant plumes that have been stabilized and are being degraded by natural attenuation. Even states such as California are applying the mixing-zone concept at sites where groundwater

is not likely to be used for drinking water, and where natural attenuation is reducing contaminant concentrations. RPO evaluations should consider the mixing-zone concept at sites where land and groundwater use can be controlled and the plume appears to be stable or receding. At DNAPL sites the primary goals should be to contain contamination and to gradually "shrink" the mixing zone.

4.3 COMMUNITY INVOLVEMENT

Both CERCLA and RCRA require community involvement in ongoing remediation activities including improvements and modifications to remediation systems or remedial action objectives. CERCLA 5-year ROD reviews must be completed with formal public notification and the results of the ROD review must be available for public review (40 CFR 300.43). According to Appendix F of the EPA's *Five-Year Review Guidance (March, 1998)*, the ROD review team should use this as an opportunity to discuss the site remediation progress with the local community. This guidance also recommends that the degree of community involvement will vary with the nature of the site. For example, sites on facilities with the potential for land transfer will require greater community interaction than low-risk sites on active installations.

Community involvement in the RCRA permit modification process is addressed in 40 CFR 270.42. In general, Class I permit modifications do not require public participation. Class II and Class III modifications require formal 60-day public comment periods. The local restoration advisory board (RAB)

is the best forum for discussing RPO findings and their impact on ROD reviews and RCRA permits. A spokesperson for the RPO evaluation team can be invited to the public meeting to provide technical support for the DoD site manager.

APPENDIX A

KEY DOCUMENTS AND REFERENCES

KEY DOCUMENTS AND REFERENCES

Although many of these documents are not yet loaded on the AFCEE website, the goal will be to have key documents loaded so they can be easily downloaded by the user. The EPA's Technology Innovation Office website (www.epa.gov/swertio1/htm) provides additional RPO information.

REGULATORY REQUIREMENTS FOR RPO

- EPA Five-Year Review Guidance (Version 3., April 1999).
- 40 CFR 270.40-62 Changes to RCRA Permits
- EPA Guidance for Evaluation of Federal Agency Demonstrations that Remedial Actions are Operating Properly and Successfully Under CERCLA Section 120(h)(3) (Interim, August 1996).
- EPA Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, EPA/540-R-93-080, Sept 1993.
- EPA, Updating Remedy Decisions at Select Superfund Sites- Summary Report FY96-97, Groundwater Remedy Updates Presentation by Matthew Charsky, November 1998.
- EPA Closeout Procedures for National Priority List Sites, EPA/540/R-95/062, (Interim Final, August 1995).
- EPA Guidance on Preparing Superfund Decision Documents, EPA/540/G-89/007, (Interim Final, July 1989).
- DoD, Guide to Establishing Institutional Controls at Closing Military Installations (1997).
- DoD, "The Environmental Site Closeout Process" (Interim Document, November 1998).
- Air Combat Command Installation Restoration Program Site Closure Guidance Manual (Interim Final, October 1997).
- Draft Air Force Property Transfer Guidance: Certification of When as Environmental Cleanup Remedy is in Place and Operating Properly and Successfully (OPS), Issued by AFBCA/EV in January 1997.

RISK-BASED REMEDIATION GUIDANCE

- Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites, ASTM 1739-95, December 1996 edition.

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- AFCEE Chemical and Site-Specific Risk Assessment (CSSRA) Protocol, Under development.
 - AFCEE Handbook for Remediation of Petroleum-Contaminated Sites (A Risk-Based Strategy), April 1998.

PUMP-AND-TREAT RPO GUIDANCE

- EPA, General Methods for Remedial Operations Performance Evaluations, EPA/600/R-92/002, January 1992.
- Keely, J.F., Performance Evaluaitons of Pump-and –Treat Remediations, EPA Environmental Engineering Sourcebook, EPA/540/4-89/005.
- EPA Methods for Monitoring Pump-and-Treat Performance, EPA/600/R-94/123, June 1994.
- Driscoll, F.G. 1986. *Groundwater and Wells*. The Johnson Division. St. Paul, Minnesota. 2nd ed, 1,089 pp.
- Roscoe-Moss Company. 1990. *Handbook of Ground Water Development*. John Wiley & Sons, Inc. New York. 493 pp.

DNAPL/LNAPL GUIDANCE

- AFCEE, Engineering Evaluation and Cost Analysis for the Bioslurping Initiative, March 1997.
- AFCEE, Light, Non-Aqueous-Phase Liquid Weathering at Various Fuel Release Sites, Jan 1999 Draft Under Review by AFCEE.
- EPA Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, EPA/540-R-93-080, Sept 1993.
- Freeze, R.A., McWhorter, D.B., “A Framework for Assessing Risk Reduction Due to DNAPL Mass Removal from Low-Permeability Soils”, Ground Water, Jan-Feb 1997, pp. 111-119.

SOIL VAPOR EXTRACTION/BIOVENTING RPO GUIDANCE

- AFCEE Soil Vapor Extraction Optimization Guidance, June 2001.
- EPA, Soil Vapor Extraction Enhancement Technology Resource Guide, EPA/542-B-95-003, October 1995.
- Johnson, P.C. et al. “A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil-Venting, Systems, Groundwater Monitoring Review, Spring 1990.
- Air Force Bioventing Principles and Practice Manual, Sept. 1995.

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- AFCEE Bioventing Performance and Cost Results From Multiple Air Force Test Sites, June 1996.
 - AFCEE Guidance on Soil Vapor Extraction Optimization, June 2001.

ABOVEGROUND TREATMENT SYSTEMS RPO

- Kroopnick, P.M., "Selecting the Appropriate Abatement Technology (for SVE)", Pollution Engineering, November 1998, pp36-40.
- Duplancic, N., "Automatic Savings", Civil Engineering, June 1998, pp55-57.

SITE AND SYSTEM MONITORING (OPTIMIZATION AND STATISTICAL METHODS)

- AFCEE Long-Term Monitoring Optimization Guide, (October 1997)
- AFCEE Remedial Process Optimization Quality Assurance and Field Procedures Protocol (Draft, Nov 1998).
- AFCEE Monitoring Decision Support Systems, A Software Package under development by Groundwater Services Inc. for AFCEE. Expected Release October 2000.
- EPA, Methods for Evaluating the Attainment of Cleanup Standards Volume 2: Ground Water, EPA-R-92-14, July 1992.
- EPA, Guidance for Data Quality Objectives, EPA/600/R-96/055
- EPA Field Sampling and Analysis Technologies Matrix and Reference Guide, EPA/542/B-98/002.
- EPA Soils Screening Guidance, EPA/540/R-95/128, May 1996.

NATURAL ATTENUATION

- AFCEE Technical Protocol for Implementing Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Groundwater. 1995.
- EPA Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, (September 1998)
- EPA OSWER Directive 9200.4-17: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, (Interim Final Dec 1997).

COST-BENEFIT ANALYSIS

- EPA Guide to Documenting and Managing Cost and Performance Information for Remediation Projects, EPA-542-B-98-007 , October 1998.

APPENDIX B

EXAMPLE RPO STATEMENTS OF WORK

EXAMPLE STATEMENT OF WORK FOR PHASE I REMEDIAL PROCESS OPTIMIZATION (RPO)

The following language is intended to supplement existing operations and maintenance contracts for remediation systems and to clearly identify Phase I RPO tasks to the operating contractor. The purpose of Phase I RPO is to improve the monitoring, evaluation, and reporting of remediation progress at existing remediation sites. A complete description of the RPO process is found in the “Remedial Process Optimization Handbook” prepared by the Air Force Center for Environmental Excellence. Air Force site managers will be responsible for customizing this generic SOW language to accurately reflect site-specific requirements.

(Sample Scope of Work)

1.0 INTRODUCTION

The purpose of this SOW is to ensure that appropriate data are collected and analyzed from remediation systems so that the overall protectiveness and effectiveness of the site remedy can be assessed. The routine collection and analysis of site data has been designated as Phase I of the overall remedial process optimization (RPO) program. The entire RPO program is described in the “Remedial Process Optimization Handbook” prepared by the Air Force Center for Environmental Excellence. The RPO program is intended to produce multiple benefits including better tracking of remediation progress, reevaluation of cleanup goals, reduced O&M costs, continued protectiveness, and accelerated site closure. The success of this program rests upon the collection of appropriate site O&M data and the professional interpretation of that data in the evaluation of remedy protectiveness and effectiveness.

2.0 SCOPE

2.1 General Scope

In carrying out this work assignment, the Contractor shall furnish the necessary personnel, services, equipment and material to accomplish the following general tasks:

- Operate, maintain, and monitor the remediation system in a cost-effective and protective manner and in accordance with current regulatory requirements;

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- Collect remediation system operations, site monitoring, and cost data that are required to evaluate system effectiveness. Input these data using the AFCEE Performance Tracking Tool (PTT) specified in Appendix F of the Air Force Remedial Process Optimization Handbook;
 - Prepare an annual remedial system performance evaluation that describes the current protectiveness of the remedy and its general effectiveness at meeting remedial performance objectives and final cleanup goals.

2.2 Specific Scope

2.2.1 The Contractor shall operate, maintain, and monitor all remediation systems in a manner that achieves current performance objectives at the lowest possible cost while collecting adequate data to assess the effectiveness of individual system components as well as the overall reduction in contaminants from the subsurface. This shall include making system modifications to optimize performance and updating the site monitoring and analytical protocols to collect appropriate data for system evaluation and regulatory reporting. System or monitoring modifications shall not be implemented without regulatory approval (if required) and written approval of the contracting officer.

2.2.2 The Contractor shall collect the following remediation system operations, site monitoring, and cost data and input these data into the PTT spreadsheets specified in Appendix F of the Air Force RPO Handbook (or equivalent data collection system specified by the MAJCOM or AFBCA).

- a. A table summarizing the concentrations of contaminants of concern at individual groundwater monitoring wells, soil gas vapor monitoring points, and extraction wells. The table will provide historical concentrations at each monitoring point and extraction well and will be used to track changes in concentration of contaminants over the lifetime of the system. Only contaminants that exceed cleanup goals should be listed, and the table should include the target cleanup goals for each contaminant;
- b. A graph that depicts the changes in concentration over time of an indicator contaminant at several key monitoring well locations, including the source area. An indicator contaminant is generally the chemical that is expected to be the most difficult to clean up to its remediation goal.
- c. A graph showing the total mass of contaminants removed to date for the entire system and from each extraction well. This will be compared to initial estimates of contaminants in the subsurface;
- d. An updated site map showing water levels and the capture radius for groundwater extraction wells. For soil vapor extraction (SVE) systems, produce an updated site map showing the area of vacuum influence. For bioventing systems, a map showing the area and depths of oxygen influence;
- e. A summary table of extraction/injection flow rates at individual wells and the total flow treated and total contaminant mass removed;

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- f. A summary of influent and effluent data from all aboveground treatment systems, including total mass of contaminants destroyed and/or discharged. The summary should also compare effluent values to regulated discharge limits;
 - g. A graph showing the cost per pound of contaminant removed; and,
 - h. An itemized accounting of annual O&M costs. Cost data should be entered into the technology-specific PTT template (see Appendix F). These data will be available for environmental manager's review and for determining future requirements and cost-saving opportunities.

2.2.3 The Contractor shall prepare an annual performance evaluation letter report summarizing RPO activities, including the data specified in para. 2.2.2 above. The report shall contain a statement regarding the current protectiveness of the site remedy and a statement that the remediation system is in compliance with applicable regulatory requirements. Attachment 1 provides additional information on the required contents of the annual summary report.

3.0 APPLICABLE DOCUMENTS

3.1 Handbook

The Air Force RPO Handbook provides guidelines for completing both Phase I and Phase II RPO evaluations and is considered the primary reference for this work.

3.2 Compliance Documents

The Contractor shall comply with all federal, state, and local regulatory agency requirements and regulations pertaining to the operation, maintenance, and monitoring of remedial systems and the reporting of remedial activities. Nothing in this SOW shall release the contractor from complying with existing regulatory requirements.

3.3 Guidance Documents

The following documents also shall be used as guidance when complying with the requirements of this SOW:

- a. EPA Five Year Review Guidance (Third Version, April 1999)
- b. EPA Guidance for Evaluation of Federal Agency Demonstrations that Remedial Actions are Operating Properly and Successfully Under CERCLA Section 120(h)(3)(Interim, August 1996)

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- c. EPA Guide to Documenting and Managing Cost and Performance Information for Remediation Projects, EPA 542-B-98-007, October 1998.
 - d. Air Force Bioventing Principles and Practice Manual, Sept 1995.
 - e. AFCEE Long-Term Monitoring Optimization Guide, October 1997.
 - f. AFCEE Remedial Process Optimization Quality Assurance and Field Procedures Protocol

3.4 Base Specific Documents

The Contractor shall be responsible for obtaining and reviewing copies of site specific documents such as Feasibility/Corrective Measures Studies, Engineering Evaluations/Cost Analysis, Records of Decisions (RODs), RCRA Permits, remedial designs and O&M manuals.

4.0 DELIVERABLES

4.1 Performance Tracking Tool

The Contractor shall maintain a PTT file for each site in accordance with Appendix F of the Air Force Remedial Process Optimization Handbook. This data will be updated quarterly and electronically transmitted to the Air Force site manager when requested.

4.2 Annual Phase I Performance Evaluation Report

The Contractor shall prepare an annual performance evaluation report that:

- a. provides an organized summary of system performance and cost data;
- b. provides an evaluation of the progress of the system toward achieving performance criteria and the ultimate remediation goals for the site; and
- c. recommends system improvements/optimizations and a more detailed Phase II RPO evaluation when needed.

If annual performance evaluations are already being provided to a regulatory agency, portions of the Phase I performance evaluation can be combined with this report. Results of the Phase I evaluation will be documented using a simple letter report format that is customized for the specific remedial system being evaluated. Printouts of annual site performance and cost data (PTT spreadsheets and graphs) shall be provided as an attachment. An example letter report outline for a Phase I performance evaluation for a SVE system is provided as Atch 1.

5.0 MEETINGS

The Contractor shall brief the results of the annual Phase I performance evaluation to the Air Force site manager. The briefing will not exceed two hours and will take place at _____.

6.0 CONTRACTOR CAPABILITIES

The Contractor shall ensure that all personnel involved in the operation, maintenance and monitoring of remediation systems are thoroughly trained in their tasks and comply with applicable Occupational Safety and Health Administration (OSHA) health and safety requirements (as specified in the site health and safety plan). The annual Phase I performance evaluation shall be completed by a qualified engineer or scientist with at least 5 years of experience with remediation system design, construction, or operation.

**ATTACHMENT 1. EXAMPLE PHASE I PERFORMANCE
EVALUATION LETTER REPORT OUTLINE (For SVE System)**

1.0 SITE OVERVIEW

- 1.1 Remedial Action Objectives
- 1.2 Remedial System Description

2.0 PROTECTIVENESS EVALUATION

- 2.1 Current Protectiveness of Remedy
- 2.2 Current Regulatory Compliance

3.0 SYSTEM PERFORMANCE EVALUATION

- 3.1 SVE Influent VOC Concentration and Flow Rate Trends
- 3.2 VMP (*In Situ*) Concentration Trends
- 3.3 Vacuum Influence Overlay
- 3.4 Mass Removal Estimates
- 3.5 Progress Toward Cleanup Milestones/Closure Criteria
- 3.6 Vapor Treatment Effluent vs Discharge Limits

4.0 COST EVALUATION

- 4.1 Summary Table of Annual O&M Costs
- 4.2 Explanation of Cost Increases/Decreases

5.0 RECOMMENDATIONS

- 5.1 Optimization Activities
- 5.2 Cost Avoidance Opportunities
- 5.3 Need for Phase II RPO Evaluation

Appendix A – Performance Tracking Tool Output File

EXAMPLE STATEMENT OF WORK FOR PHASE II REMEDIAL PROCESS OPTIMIZATION (RPO)

The following example SOW is intended to assist Air Force environmental managers in preparing procurement documents to retain engineering consultants for Phase II RPO evaluations. Normally, the Phase II evaluation will be completed by an independent contractor who was not involved in the original remedial system design or in the current operation of the system. The purpose of Phase II RPO evaluations is to provide an independent and detailed analysis of remediation systems including: a review of cleanup goals, performance criteria, and conceptual site models, system effectiveness and efficiency evaluations, identification of potential system optimizations or new technologies. A complete description of the RPO process is found in the “Remedial Process Optimization Handbook” prepared by the Air Force Center for Environmental Excellence. Air Force site managers will be responsible for customizing this generic SOW language to accurately reflect site-specific requirements.

(Sample SOW)

1.0 INTRODUCTION

The purpose of this SOW is to retain professional engineering services (the Contractor) to complete all aspects of a Phase II remedial process optimization (RPO) evaluation so that the overall protectiveness and effectiveness of the site remedy can be assessed. The RPO program is intended to produce multiple benefits including better tracking of remediation progress, reevaluation of cleanup goals, reduced O&M costs, continued protectiveness, and accelerated site closure. The success of this program rests upon the collection of appropriate site O&M data and the professional interpretation of that data in the evaluation of remedy protectiveness and effectiveness. The routine collection and analysis of site data is included in Phase I of the RPO program. Phase II RPO evaluations will be completed at remediation sites that are obviously falling short of performance criteria, at sites which are nearing key regulatory reviews (i.e. 5-Year Record of Decision (ROD) Reviews, RCRA permit reapplications, and at BRAC sites which are in the process of fulfilling Operating Properly and Successfully (OPS) demonstration criteria. The results of Phase II RPO evaluations will be used as the technical foundation for these mandated regulatory reviews. The entire RPO program is described in the “Remedial Process Optimization Handbook” prepared by the Air Force Center for Environmental Excellence. Section 3 of this Handbook describes the purpose, primary activities, and responsibilities of the Phase II RPO evaluation.

2.0 SCOPE

2.1 General Scope

In carrying out this work assignment, the Contractor shall furnish the necessary personnel, services, equipment, and material to accomplish the following general tasks:

- Review key regulatory decision documents and historical monitoring and system performance data and complete a site visit to become familiar with site complexities and remediation system operations. Prepare a Phase II work plan outlining site-specific evaluation activities;
- Review the ultimate remediation goals for the site to ensure they are appropriate and reflect current regulatory options;
- Complete a design review and update of the conceptual site model. Review current performance criteria. If no performance criteria exist, develop performance criteria that are clearly defined and measurable;
- Evaluate remedial system effectiveness to determine if ultimate cleanup goals can be achieved with the existing remedy (or are new technologies required);
- Evaluate site and system monitoring and analytical protocols to determine if they are appropriate for the in-place remedy and remediation time frame;
- Evaluate system efficiencies and identify both short-term and long-term optimization opportunities;
- If needed, identify new regulatory approaches and/or new technical approaches to achieve the ultimate remediation goals for the site and perform a cost-benefit analysis for recommended changes; and,
- Prepare a Phase II final report which summarizes system protectiveness and effectiveness evaluations and recommends new regulatory and technical approaches, including short- and long-term optimization opportunities.

2.2 SPECIFIC SCOPE

2.2.1 The Contractor shall review key regulatory documents such as RI/FS/CMS documents, RODs, RCRA corrective action permits, remedial designs, site monitoring data, and remedial system performance data. The Contractor shall collect and copy as much of this data as possible during the initial site visit. During this initial site visit the Contractor shall provide a briefing to Air Force site manager and remediation system operating contractor describing the overall objectives of the RPO program. The site visit will allow the RPO Phase II Contractor to become familiar with site complexities and the layout of the remediation system(s). Based on this data review and site visit, the Contractor shall prepare a draft Phase II RPO work plan describing the evaluation activities proposed for the site. The work plan will clearly identify any support required from the base or operating contractor.

2.2.2 The Contractor shall review regulatory decision documents to determine the regulatory history of the site and the basis for all cleanup goals. The contractor shall review applicable federal, state, and local regulations and policies to determine if site cleanup goals can be updated to reflect current regulatory practices (particular emphasis should be given to revising cleanup standards based on new risk-based and technical impracticability policies). The Contractor shall review current risk exposure and toxicological information to determine if initial risk evaluations remain valid. If appropriate, the Contractor shall determine and describe the regulatory process for revising/updating site cleanup goals.

2.2.3 The Contractor shall review the remedial system design and design assumptions including estimates of remediation time frames. The review shall include an update of the conceptual site model, key design assumptions, and current performance criteria based on the latest site monitoring data and actual operating data from the system. If performance criteria do not exist or are obsolete, the Contractor shall develop new performance criteria.

2.2.4 The Contractor shall review the site monitoring plan and analytical protocols specified in the Sampling and Analysis Plan (SAP) to determine if the frequency and type of analysis are appropriate for monitoring ongoing remediation progress. This evaluation will be completed in accordance with the AFCEE Long-Term Monitoring Optimization Guidance.

2.2.5 Using the evaluation methods described in the RPO Handbook and other appropriate analysis tools, the contractor shall evaluate remedial system effectiveness to determine if site cleanup goals can be achieved with the existing remedy within a reasonable time-frame. If the current technical approach is effective, or potentially effective, the Contractor shall recommend continued operations and system optimizations that improve contaminant removal or cost-effectiveness. If the current technical approach is not effective, and will never be effective, the Contractor shall recommend a new regulatory or technical approach for the site. A cost-benefit analysis shall be completed for each recommendation for optimization or change in regulatory or technical approach.

2.2.6 The Contractor shall prepare a Phase II report which summarizes the activities, findings, and recommendations of the Phase II evaluation team. The report should identify both short- and long-term optimization opportunities and the cost/benefits of each oppor-

tunity. The report shall provide an implementation plan and identify additional studies and data needs that are beyond the scope of the Phase II RPO evaluation. Attachment 1 provides additional details on the content of the Phase II report.

2.3 Other Environmental Activities

If required, the Contractor shall collect and analyze environmental samples from the site or from aboveground remediation systems. The government has estimated that the following type and quantity of laboratory analysis will be required for this site:

<u>Type of Analysis</u>	<u>No. of Samples</u>
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(Site Specific Information)

The Contractor shall be required to collect additional samples that are necessary to perform required quality assurance and quality control procedures. (see para 7.0 for laboratory requirements)

2.4 Special Notifications

(as required by the contracting officer and technical manager)

2.5 Worksite Requirements

(as required by the base and technical manager)

3.0 APPLICABLE DOCUMENTS

3.1 Handbook

The Air Force Remedial Process Optimization Handbook provides guidelines for completing both Phase I and Phase II RPO evaluations and is considered the primary reference for this work.

3.2 Compliance Documents

The Contractor shall comply with all applicable federal, state and local regulatory agency requirements and regulations pertaining to the operation, maintenance, and monitoring of remedial systems and the reporting of remedial activities. Nothing in this SOW shall release the Contractor from complying with existing regulatory requirements.

3.3 Guidance Documents

The following documents also shall be used as guidance when complying with the requirements of this SOW:

See Appendix A of RPO Handbook

3.4 Base Specific Documents

The Contractor shall be responsible for obtaining and reviewing copies of site specific documents such as RI/FS/CMS studies, EE/CAs, RODs, RCRA Permits, remedial designs and O&M manuals.

4.0 DELIVERABLES

4.1 Work Plan for Phase II Activities

The Contractor shall prepare a draft and final work plan describing the Phase II evaluation activities to be completed by the Phase II team. The draft work plan will be reviewed as an internal Air Force document and comments provided to the contractor. If the Contractor is required to collect and analyze environmental samples, the existing Sampling and Analysis Plan for the site (or Base) will be incorporated into the Phase II work plan by reference.

(Optional: At some facilities, the Air Force may include the lead regulatory agency in the work plan review. In this the case, the contractor shall be responsible for producing a draft final work plan for regulatory review before producing the final work plan.)

4.2 Phase II Evaluation Report

The Contractor shall prepare a draft, draft final, and final Phase II RPO evaluation report. An example outline for this report is included as Attachment 1. The draft report will be reviewed as an internal Air Force document and comments provided to the contractor. At the discretion of the site manager, the draft final document will be reviewed by the lead regulatory agency and regulatory comments incorporated into the final report. (Optional: The final versions of Phase II evaluation report will be provided in both a hard copy and a web-based electronic “pdf” format.)

4.3 Meeting Minutes

The Contractor shall be responsible for generating meeting minutes documenting all items discussed at the meetings and include a list of meeting attendees.

4.4 Presentation Materials

The Contractor shall prepare and present briefing packages at the initial site visit meeting and for the presentation of Phase II evaluation results. As a part of the presentation materials, the Contractor shall prepare paper copies of all slides and overheads. Prepare photo documentation including site photos, existing treatment system photos, field activities, etc.

4.5 Monthly Financial and Management Reports

(as required by the contracting office and technical manager)

4.6 Project Schedules

(as required by the contracting office and technical manager)

5.0 MEETINGS, CONFERENCES, SITE VISITS

5.1 Initial Site Visit

The Contractor shall attend a two-day initial site visit. The Contractor shall prepare and present a briefing describing the general Phase II RPO activities to the base and the operating contractor. The visit will also be used to collect important site data for preparation of the work plan.

5.2 Field Evaluation

The Contractor shall mobilize to the site to conduct RPO evaluation activities such as inspection of extraction and treatment systems, collection of environmental samples, and completion of field tests to determine system effectiveness and optimization opportunities.

5.3 Phase II Evaluation Report Briefing

Following completion of the draft Phase II Evaluation Report, the Contractor shall prepare and present the results of the Phase II RPO evaluation to Air Force representatives, base operating contractors, and regulatory officials (if invited by the Air Force). The one-day meeting will be held at the base or a location specified by the government.

5.4 Regulatory and Public Meetings

The Contractor shall prepare for and attend one additional regulatory or public meeting at the request of the government. The primary purpose of this meeting will be to gain a consensus for the acceptance and implementation of Phase II RPO recommendations. The Contractor shall be prepared to present the results of the Phase II Evaluation Report at this meeting.

6.0 CONTRACTOR CAPABILITIES

The Contractor shall ensure that all personnel involved in the Phase II evaluation team have a minimum of 5 years of experience and have attained professional registrations in their respective specialties. At a minimum, the Contractor shall include the following professionals on the Phase II evaluation team:

- a geologist or hydrogeologist;
- an environmental or chemical process engineer;
- a groundwater chemist or geochemist; and
- a statistician

If environmental sampling is required, Contractor personnel shall be thoroughly trained in the procedures specified in the SAP and comply with applicable Occupational Safety and Health Administration (OSHA) health and safety requirements (as specified in the site health and safety plan).

7.0 LABORATORIES

If laboratory analysis are required in the performance of the assigned tasks, the contractor shall only utilize labs that meet the appropriate QA/QC requirements for the required data. The contractor shall be responsible for execution of the QA/QC procedures. Laboratories used by the contractor may be subject to on-site audits. The Contractor shall verify that the data quality objectives specified in the approved Sampling and Analysis Plan (SAP) are satisfied. In most cases the existing SAP governing the remedial system-operating contractor shall be used for sampling and analysis work under the RPO contract. (other laboratory requirements may be added as needed)

ATTACHMENT 1-EXAMPLE PHASE II RPO EVALUATION OUTLINE

1.0 Project Overview

- 1.1 Purpose and Scope
- 1.2 Site History
- 1.3 Remedial System and Monitoring Program Description

2.0 Review of Conceptual Site Model

- 2.1 Current CSM
- 2.2 Trends in Contaminant Concentrations and Movement
- 2.3 Natural Attenuation Evaluation
- 2.4 Exposure Pathways and Receptors
- 2.5 Refinement of CSM

3.0 Evaluation of Cleanup Goals

- 3.1 Review of Regulatory Decision Document
- 3.2 Remedial Action Objectives
- 3.3 New Regulatory Options
- 3.4 Evaluation of Risk-Based Goals
- 3.5 Recommended Revisions to Cleanup Goals

4.0 Evaluation of Remedial System

- 4.1 Influent Concentration and Flow Trends
- 4.2 Monitoring Well Concentration Trends
- 4.3 Equilibrium Test Results
- 4.4 Treatment System Effluent Trends vs. Discharge Limits
- 4.5 Performance Criteria/Progress Milestones
- 4.6 Performance To Date
- 4.7 Determination of Effectiveness
- 4.8 Optimization Opportunities
- 4.9 New Technology/New Approach Opportunities
- 4.10 Recommendation for Improving Effectiveness

5.0 Cost Evaluation

- 5.1 Summary of Annual OM&M Costs
- 5.2 Cost-Benefit Analysis of Proposed System Changes

6.0 Recommendations (as appropriate)

- 6.1 Optimization Activities
- 6.2 New Technology Opportunities
- 6.3 Revised Cleanup Goals or Approach such as TI Waiver
- 6.4 New Technical Approach such as Source Isolation/Plume Containment

7.0 Implementation Plan (as appropriate)

- 7.1 Five-Year ROD Review
- 7.2 RCRA Permit Reapplication
- 7.3 OPS Demonstration
- 7.4 Schedule for Implementation

APPENDIX C
US ARMY CORPS OF ENGINEER
REMEDIAL SYSTEMS EVALUATION CHECKLISTS

The home page of the USACE website is provided along with a listing of the 22 individual technology checklists that are available through the website. An example checklist for aboveground treatment systems is also provided.

The USACE website address is:

www.environmental.usace.army.mil/library/guide/reschk/rsechk.html

APPENDIX D

AFCEE LONG-TERM MONITORING OPTIMIZATION GUIDE

An outline of this document is provided to describe its general contents. The document can be downloaded from the AFCEE website:

www.brooks.af.mil/er/toolbox.htm

APPENDIX E

AFCEE REMEDIAL PROCESS OPTIMIZATION FIELD PROCEDURES AND QUALITY ASSURANCE PROTOCOL

Purpose of this document is to develop data quality objectives (DQOs) and performance based measurement systems (PBMS) that are appropriate for field data collected at active remediation systems. An outline of this document is provided to describe its general contents. The document can be downloaded from the AFCEE website:

www.brooks.af.mil/er/toolbox.htm

AIR FORCE REMEDIAL PROCESS OPTIMIZATION FIELD PROCEDURES AND QUALITY ASSURANCE HANDBOOK

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APPENDIX F

PERFORMANCE TRACKING TOOL

(Identified Requirement-Under Development)

PERFORMANCE TRACKING TOOL

AFCEE is preparing a simple Microsoft Excel spreadsheet application known as the Performance Tracking Tool (PTT) to assist operating contractors and site managers with tracking key performance and cost data for remediation projects. This PC-based spreadsheet package will be available for downloading from the AFCEE website www.brooks.af.mil/er/toolbox.htm and can be used to prepare annual Phase I RPO evaluation reports. Once the data has been entered into the PTT spreadsheets it can be easily displayed using a menu of graphing options. Once completed the site-specific spreadsheet file can be electronically transferred to MAJCOMs or appropriate headquarters. The following input tables and graphic displays are examples of input data and output of the AFCEE sample PTT application.

DATA INPUT TABLES

1. General Site Information and Cleanup Criteria
2. Historical Monitoring Well Data for Indicator Contaminant
3. Extraction Well Performance Data
4. Treatment System Performance Data
5. Annual O&M Cost Data

GRAPHIC DISPLAY OPTIONS

1. Individual Monitoring Well Contaminant vs Time
2. Individual Extraction Well Contaminant vs Time
3. Extraction Well Contaminant Mass Removal vs Time
4. Total Mass Removal vs Time
5. Treatment System Influent and Effluent vs Time
6. Annual O&M Costs vs Time
7. Cost per Pound of Contaminant Removed and Treated

APPENDIX G
OVERVIEW OF STATISTICAL METHODS FOR
EVALUATING GROUNDWATER MONITORING NETWORKS

OVERVIEW OF STATISTICAL METHODS FOR EVALUATING GROUNDWATER MONITORING NETWORKS

The relative success of any remediation system, and its components (including the groundwater monitoring network) must be judged based on its ability to achieve the stated objectives of the system. One of the most important purposes of a remedial groundwater monitoring program is to confirm that the contaminant plume is behaving as predicted. The design of an effective groundwater monitoring program therefore involves locating monitoring points and developing a site-specific strategy for groundwater sampling and analysis so as to maximize the amount of relevant information that can be obtained while minimizing the incremental costs. If the groundwater remediation system is effective, then over the long term, groundwater monitoring data should demonstrate a clear and meaningful decreasing trend in contaminant concentrations at appropriate monitoring points.

Any meaningful analysis of the performance of a groundwater monitoring program should include evaluating (1) long-term temporal trends in chemical concentrations at one or more points within or outside of the remediation zone, as a means of monitoring the performance of the remedial measure (*temporal evaluation*), and (2) the extent to which contaminant migration is occurring, particularly if a potential exposure point for a susceptible receptor exists (*spatial evaluation*). These two primary objectives can be evaluated quantitatively using statistical techniques. However, it is important to note that there may be other important considerations associated with a particular monitoring network that are most appropriately addressed through a qualitative hydrogeologic evaluation of the groundwater monitoring network. The qualitative evaluation may consider such factors as hydrostratigraphy, locations of potential receptors with respect to a dissolved plume, and the direction(s) and rate(s) of contaminant migration. Consequently, the evaluation of a groundwater monitoring network should be conducted in stages to address each of the objectives and considerations of monitoring: a qualitative evaluation should be completed first, followed in succession by quantitative temporal and spatial evaluations.

The objective of this appendix is to summarize the various statistical approaches that may be used to quantitatively evaluate both the temporal and spatial aspects of monitoring data collected under ongoing groundwater monitoring programs. This summary is not exhaustive in terms of the possible options available to quantitatively evaluate groundwater monitoring data that are being collected to monitor the progress of remedial system performance. However, the approaches and methods detailed within this appendix have been applied easily and successfully at many Air Force facilities to optimize the performance of, and possibly even reduce the long-term operating costs associated with, groundwater monitoring systems. The summary includes a review of the site conditions that may influence what approaches and methods would be most appropriately applied for optimization analysis.

G.1 MONITORING AND REMEDIATION OPTIMIZATION SYSTEM (MAROS) SOFTWARE

The MAROS software is a Microsoft Access® database application that was developed by AFCEE to assist users with groundwater data trend analysis and long-term monitoring optimization at contaminated groundwater sites. The software program is consistent with AFCEE's *Long-Term Monitoring Optimization Guide* (Version 1.1). AFCEE developed MAROS as a decision support tool, so that a site-specific monitoring program that is currently tracking the occurrence of contaminant migration in groundwater could be optimized on the basis of a statistical analysis that accounts for hydrogeologic conditions, groundwater plume stability, and available monitoring data.

The MAROS software consists of a set of small programs (macros) that operate within the Microsoft Access® electronic database environment to perform certain mathematical or statistical functions using user-supplied environmental data. MAROS makes extensive use of graphical user interfaces (GUIs), and was designed to be a user-friendly tool. The software may be easily and appropriately applied by both technical and non-technical personnel to organize, preliminarily evaluate, and present groundwater monitoring data.

Temporal data (i.e., contaminant concentrations measured at groundwater sampling locations at different points in time) can be examined visually, or with statistical tests, to evaluate plume stability. Temporal chemical concentration data can be evaluated by plotting contaminant concentrations through time for individual monitoring wells, or by plotting contaminant concentrations versus downgradient distance from the contaminant source for several wells along the groundwater flowpath, over several monitoring events. If removal of contaminant mass is occurring in the subsurface as a consequent of attenuation or operation of a remediation system, mass removal will be apparent as a decrease in contaminant concentrations through time at a particular sampling location, as a decrease in contaminant concentrations with increasing distance from source areas, or as a change in the suite of contaminants through time or with increasing migration distance. Plotting temporal concentration data is recommended for any analysis of plume stability (Wiedemeier and Haas, 1999); however, visual identification of trends in plotted data may be a subjective process, particularly (as is likely) if the concentration data do not have a uniform trend, but are variable through time.

The possibility of arriving at an incorrect conclusion regarding plume stability on the basis of visual examination of temporal concentration data can be reduced by examining temporal trends in chemical concentrations using various statistical procedures, including regression analyses and the Mann-Kendall test for trends. The Mann-Kendall non-parametric test (Gibbons, 1994) is well suited for application to the evaluation of environmental data because the sample size can be small (as few as four data points), no assumptions are made regarding the underlying statistical distribution of the data, and the statistic can be calculated at a specified level of confidence to evaluate whether a temporal trend is present in contaminant concentrations detected through time in samples from an individual well. If a trend is determined to be present, a non-parametric slope of the trend line (change per unit time) can also be estimated using the test procedure. A negative slope (indicating decreasing chemical concentration through time) or a positive slope (indicating increasing chemical concentrations through time) provides statistical confirmation of temporal trends that may have been identified visually.

The MAROS software supports both parametric analyses (using linear regression) and non-parametric analyses (using the Mann-Kendall test for trends) in order to assess the statistical significance of temporal concentration trends. The MAROS software also can be used to support simple spatial analyses of groundwater monitoring data. Spatial statistical techniques can be used to assess the relative value of the data generated during monitoring, and to optimize monitoring networks. MAROS provides for a simple spatial statistical method, based on a weighted “area-of-influence” approach (implemented using Delauney triangulation), to identify optimal locations of monitoring points. Additionally, the MAROS software enables users to incorporate empirical evidence and/or modeling results into any groundwater monitoring network analysis for a site. The MAROS software has been configured to provide data analysis support related to several primary questions:

- Is the trend in the groundwater site data significant?
- How important is each well in the trend analysis?
- What is the suggested future monitoring well density, sampling frequency and duration?
- What constituents of concern (COCs) are identified at the site?
- What wells are statistically relevant to the current sampling program?

Successful application of the MAROS tool to the site-specific evaluation of a monitoring network is completely dependent upon the amount and quality of the available data (e.g., data requirements for a temporal trend analysis include a minimum of four distinct sampling events.).

G.1.1 Minimum Site-Specific Data Requirements

The United States Environmental Protection Agency (USEPA) recommends the use of conceptual site models (CSMs) to integrate data and guide both investigative and remedial actions (e.g., see USEPA, 1999). A CSM is a three-dimensional representation that conveys what is known or suspected about contamination sources, release mechanisms, and the transport and fate of those contaminants. The CSM provides the basis for assessing potential remedial technologies at a site. In the context of the MAROS software, CSM development prior to software use would facilitate analysis (as well as provide guidance for assessing the data that would best typify historical site conditions).

The CSM should include a three-dimensional representation of the source area (as a non-aqueous phase liquid [NAPL] or region of highly-contaminated groundwater), of the surrounding uncontaminated area, of ground water flow properties, and of the solute transport system based on available geological, biological, geochemical, hydrological, climatological, and of analytical data for the site (USEPA, 1998). Data on the contaminant levels and aquifer characteristics should be obtained from wells and boreholes which will provide a clear three-dimensional picture of the hydrologic and geochemical characteristics of the site. High concentrations of dissolved contaminants can be the result of

leachates, rinse waters and rupture of water conveyance lines, and are not necessarily associated with NAPLs.

At a minimum, the CSM used to support a statistical evaluation of groundwater monitoring data using MAROS must include: (1) an understanding of site-specific COCs, including their relevant source areas and transport mechanisms, (2) data on site stratigraphy and groundwater flow velocity and direction, (3) a complete delineation of the groundwater plume, (4) the locations of groundwater wells, groundwater-to-surface water discharge locations, underground utilities, or other points of potential exposure, and (5) any current or near-term receptor impact (defined as occurring in zero to two years) must be assessed. Plumes posing current or near-term impact on applicable receptors are referred for immediate evaluation of appropriate risk management measures.

Additionally, the MAROS tool requires an absolute minimum set of groundwater sampling results in order to complete the statistical analyses using the database programs (macros). Groundwater quality data from at least four wells (ASTM, 1998) in which COCs have been detected are required. The set of wells used in the analysis may include up to two wells which have not exhibited COCs during more recent sampling events being analyzed, but COCs must have been previously detected in these locations (i.e., the use of compliant point-of-compliance wells is not appropriate). However, as many wells as possible should be included in the evaluation subject to the other minimum data requirements. Additionally, data for each well included in any analysis using the MAROS software must include at least 4 measured concentrations over 6 sampling events during the time period being analyzed. For any well, data may not be missing from more than two consecutive sampling events. Guidelines given by ASTM (1998) notes that a minimum of more than one year of quarterly monitoring data of 4 or 5 wells is needed to establish a trend.

Finally, the evaluation should be based on groundwater quality data collected during at least the six most recent sampling events which satisfy the minimum groundwater data requirements (specified above). Documentation included with the MAROS software recommends consolidating multiple sampling dates within a single quarter into a single sampling event; any multiple measurements of the same constituent also should be consolidated by the user (e.g. average concentration for the consolidated sampling events). The sampling events do not need to be the same for each well.

Although the MAROS software will calculate trends for fewer than 4 wells and a minimum of 4 sampling events, it is important to realize that the computed results may not support a meaningful statistical evaluation of COC trends over time. Furthermore, the described minimum requirements only apply to “well behaved” sites; more data are typically required at most sites to obtain an accurate representation of COC trends. For example, sites with significant variability in groundwater monitoring data (due to water table fluctuation, variations in groundwater flow direction, etc.) will require more data to obtain meaningful stability trends.

G.1.2 MAROS Statistical Trend Analyses: Concentration vs. Time

Under optimal conditions, the natural attenuation of organic COCs at any site is expected to approximate a first-order exponential decay for compliance monitoring

groundwater data. With actual site measurements, apparent concentration trends may often be obscured by data scatter arising from non-ideal hydrogeologic conditions and sampling and analysis conditions. However, even though the scatter may be of such magnitude as to yield a poor goodness of fit (typically characterized by a low correlation coefficient, e.g., $R^2 \ll 1$) for the first-order relationship, parametric and non-parametric methods can be utilized to obtain *confidence intervals* on the estimated first-order coefficient, i.e., the slope of the log-transformed data.

Parametric tests such as first-order regression analysis make assumptions on the normality of the data distribution, allowing results to be affected by outliers in the data in some cases. However, parametric methods produce more accurate trend assessments than non-parametric methods when the groundwater quality data used in the trend analysis can be described by a normal distribution. Therefore, when the data is normally distributed, the parametric methods provided in the MAROS software should be utilized.

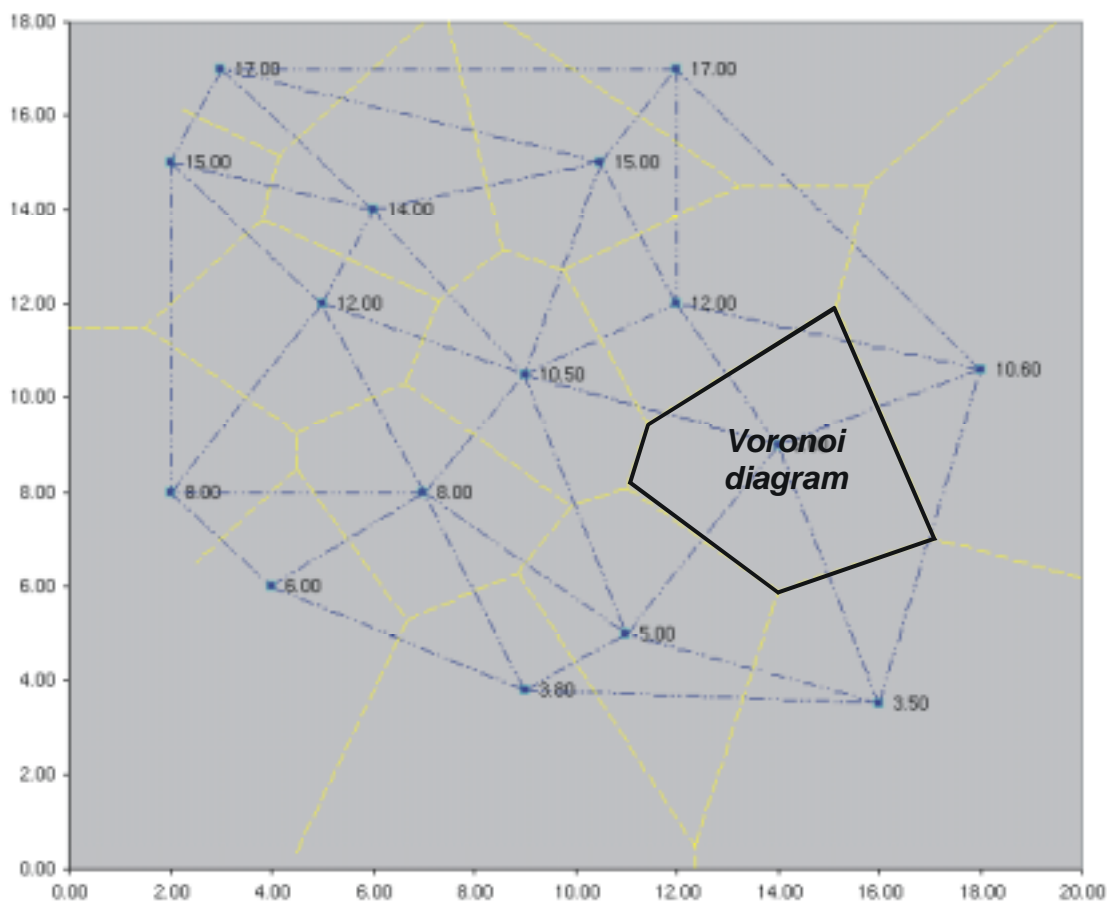
Non-parametric tests such as the Mann-Kendall test for trend are suitable for analyzing data that do not follow a normal distribution. Non-parametric methods focus on the location of the probability distribution of the sampled population, rather than specific parameters of the population. The outcome of the test is not determined by the overall magnitude of the data points, but depends on the ranking of individual data points. Assumptions on the distribution of the data are not necessary for non-parametric tests. The Mann-Kendall test for trend is a non-parametric test which has no distributional assumptions and permits irregularly spaced measurement periods. The advantage gained by this approach involves the cases where outliers in the data would produce biased estimates of the least squares estimated slope.

G.1.3 MAROS Statistical Spatial Analyses: Delaunay Method

This section of the appendix summarizes the approach developed by the authors of the MAROS software system for the determination of sampling locations, the so-called Delaunay Method. Readers interested in the details of this spatial analysis method are encouraged to review the MAROS software documentation (AFCEE, 2000).

The ultimate objective in the MAROS spatial sampling routine is to define the monitoring network configuration necessary to accurately map a contaminant plume and track any changes. Clearly, the degree of accuracy that plumes can be mapped and monitored is dependent upon the density of wells and frequency of sampling in a monitoring program. The goal of the spatial analysis module in MAROS is to identify the optimum number of wells required to maintain the desired level of accuracy in plume delineation and tracking. Consequently, the spatial analysis attempts to determine which, if any, wells could be eliminated from a monitoring network with no significant loss of information. The optimization process in MAROS based on spatial analysis is iterative.

The Delaunay method is designed to select the minimum number of sampling locations based on the spatial analysis of the relative importance of each sampling location in the monitoring network. The approach allows elimination of sampling locations that have little statistical impact on the historical characterization of a contaminant plume. As implemented in MAROS, the Delaunay method is in fact an optimization approach that deals with the reduction of redundancy only.



The Delaunay method is developed based on Delaunay triangulation, which is the triangulation of a point set with the property that no point in the point set falls in the interior of the circumcircle of any triangle in the triangulation. Delaunay triangles and the dual parts of these triangles (Voronoi diagrams) have been widely used for centuries for solving spatial distribution problems (Okabe *et al.*, 1992; Watson, 1994). In MAROS, Delaunay triangulation is first used to generate a grid for the studied site with potential sampling locations as its nodes. Then, based on the formation of Delaunay triangles and Voronoi diagrams, spatial analyses are made to determine the relative importance of each sampling location. Finally, spatially-redundant locations are eliminated from the monitoring network.

The Delaunay method performs the redundancy reduction by using an algorithm that considers all or a series of sampling events, of which optimization based on a single sampling event is a special case. Since each sampling event represents only one snapshot of the contaminant plume, all sampling events (or parts of them) need to be examined to reveal the general spatial pattern of the contaminant distribution in a specific site. This general spatial pattern is the underlying assumption for the spatial analysis. In the Delaunay method, the general pattern is determined by averaging across sampling events. In addition, since the spatial patterns of COCs may be different from each other, the optimization is performed based on each COC. Therefore, results are given separately in terms of each COC. The MAROS software summarizes the conclusions of each of these spatial

analyses in an all-in-one results table, which presents the most conservative result from all COCs evaluated.

The MAROS software will not incorporate sampling results in the spatial analysis if the coordinates of a sampling location are not available. Consequently, only sampling locations with known coordinates can be used. Additionally, the minimum number of wells required for this type of spatial analysis is six. Fewer than six wells will invalidate the Delaunay method analysis (i.e., no result will be provided).

G.1.4 Summary of Scope of MAROS Decision Matrix

MAROS uses a simple decision matrix to indicate how often wells at the site should be sampled to be sufficient for adequate groundwater monitoring. Users can compare the frequency of the sampling at their site to the suggested frequency of monitoring evaluated based on the software decision matrix. If their site has wells being sampled at a significantly higher interval, then some reduction in the sampling frequency could be applied. Note that user can apply the sampling optimization (Sample Frequency) wing of the software to perform a more rigorous analysis of the sampling frequency required for monitoring.

MAROS also uses a simple decision matrix to indicate the duration of future groundwater monitoring at the site to be sufficient prior to determination of site closure. Users can compare the projected duration of the sampling at their site to the suggested duration of monitoring evaluated based on the software decision matrix. If their site has groundwater monitoring planned for a significantly longer time period, then some reduction in the monitoring duration could be applied, subject to local and federal regulations.

Finally, the MAROS software incorporates data developed during the more rigorous spatial analysis to optimize sampling location and frequency. Wells used in the spatial analysis are identified as either important or redundant to providing the desired degree of accuracy with regard to plume delineation and monitoring.

G.1.5 Potential Application Limitations

The MAROS tool may not be suitable for application in certain types of groundwater monitoring network evaluations. For example, as noted previously, an absolute minimum of 6 monitoring wells are required for spatial analysis and at least 4 separate sampling events are required for the MAROS temporal analysis. However, these minimum data requirements may not provide sufficient information to support the statistical routines in MAROS and to fully evaluate groundwater contamination at many sites. More rigorous statistical methods described in the next section may be required.

Additionally, the database programs (macros) in MAROS can fail to produce reasonable summary statistics on groundwater data when there are a significant number of non-detected results. The MAROS software assigns the value of the detection limit or the laboratory reporting limit to analytical results reported as “not detected.” This convention potentially can generate misleading results in the temporal evaluation of monitoring data from a particular monitoring point. For example, consider a monitoring well that has been sampled routinely through some period of time. Groundwater samples from the

well have been consistently reported as “not detected” for a specific COC. Analytical methods and protocols have undergone a number of changes through the years, and these improvements have generally resulted in lower detection limits. Consistent substitution of the analytical detection limit for a value reported as “not detected” (as the MAROS software does) will result in the identification of an apparently decreasing temporal trend in chemical concentrations through time, when in fact no such trend exists. The supposed “trend” is merely an artifact of the decreases in analytical detection limits through time. Additionally, the relative importance of continuing “not detected” results at certain wells may in fact be a very important component in understanding and evaluating plume behavior. In this type of case, the convention in MAROS may actually “disguise” valuable information with inaccurate trend conclusions.

G.2 RIGOROUS ASSESSMENT OF TEMPORAL AND SPATIAL TRENDS

The value of information obtained from periodic monitoring at a particular monitoring well depends on the location of the well within (or outside of) the contaminant plume, the location of the well with respect to potential receptor exposure points, and the presence or absence of temporal trends in contaminant concentrations in samples collected from the well. The degree to which the amount and quality of information obtainable at a particular monitoring point serves the two primary objectives of monitoring (temporal and spatial objectives) must be considered in a quantitative groundwater network evaluation. For example, the continued occurrence of a contaminant in groundwater at concentrations below the detection limit at a monitoring location provides no information about temporal trends in concentrations, or about the extent to which contaminant migration is occurring, unless the monitoring location lies along a groundwater flowpath between a contaminant source and a potential receptor exposure point. Therefore, a monitoring well having a history of COC concentrations below detection limits may provide no useful information, depending on its location.

A trend of increasing contaminant concentrations in groundwater at a location between a contaminant source and a potential receptor exposure point may represent information critical in evaluating whether contaminants may migrate to the exposure point, thereby completing an exposure pathway. Identification of a trend of decreasing contaminant concentrations at the same location may be useful in evaluating decreases in a plume’s areal extent, but does not represent information that is critical to the protection of a potential receptor. Similarly, a trend of decreasing contaminant concentrations in groundwater near a contaminant source may represent important information regarding the progress of remediation near, and downgradient of the source, while identification of a trend of increasing contaminant concentrations at the same location does not provide as much useful information regarding contaminant conditions. By contrast, the absence of a temporal trend in contaminant concentrations at a particular location within, or downgradient of a plume, indicates that virtually no additional information can be obtained by continued monitoring of groundwater at that location, in that the results of continued monitoring through time are likely to fall within the historic range of concentrations that have already been detected. Continued monitoring at locations where no temporal trend in contaminant concentrations is present serves merely to confirm the results of previous monitoring activities at that location.

A more rigorous quantitative temporal analysis can be conducted on a site-specific basis by using the Mann-Kendall test to identify those wells having increasing or decreasing concentration trends for each COC. This analysis will be different than that developed using the MAROS software, as specific database conventions (i.e., detection limit substitutions) can be avoided. Additionally, this analysis should also focus on summarizing the quality of information represented by the existence or absence of concentration trends in terms of the location of each monitoring point. The analysis should be conducted to identify those monitoring points having non-detectable concentrations, decreasing or increasing concentrations, or no discernible trend in concentrations to be readily identified. Monitoring points at which chemical concentrations display no discernible temporal trend generally represent points generating the least amount of useful information. Depending on the location of the monitoring point, consistently “not detected” concentrations of chemicals through time can also represent relatively little information.

Spatial statistical techniques can also be applied to the design and evaluation of monitoring programs to assess the quality of information generated during monitoring, and to optimize monitoring networks. Geostatistics, or the theory of regionalized variables (Clark, 1987; Rock 1988; American Society of Civil Engineers [ASCE], 1990a and 1990b), is concerned with variables that have values dependent on location, and are continuous in space, but which vary in a manner too complex for simple mathematical description. The theory of regionalized variables begins from the premise that the differences in values of a spatial variable depend only on the distances between, and the relative orientations of, sampling locations -- that is, the values of a variable (e.g., concentrations of a specific COC) measured at two locations that are spatially "close together" will be more similar than values of that variable measured at two locations that are "far apart". If known sample values are used, the value of the variable (e.g., chemical concentrations) at any point within the sampled region can be estimated, in the process known as "kriging" (Clark, 1987; ASCE, 1990a and 1990b). An additional advantage of kriging as an estimation technique is that the standard deviations (“errors”) associated with the values estimated at each point in the spatial domain also are calculated during the kriging process.

Areas containing estimated concentration values having elevated standard deviations associated with them represent locations where additional information could be collected to reduce uncertainties regarding the extent of COCs in the subsurface. This observation implies that the monitoring program could be optimized by using available information to identify those areas having the greatest associated uncertainty. Conversely, sampling points can be successively eliminated from simulations, and the standard deviations examined, to evaluate if significant loss of information (represented by increases in standard deviations) occurs as the number of sampling points is reduced. Iterative application of geostatistical estimating techniques, using tentatively identified sampling locations, can then be used to generate a sampling program that would provide an acceptable level of uncertainty regarding chemical distribution across the area to be monitored, with the minimum possible number of samples collected.

One approach to this type of site-specific quantitative analysis may be to conduct a series of screening-level kriging simulations to evaluate whether the technique could be successfully applied to optimize the groundwater monitoring network. The results of these screening simulations could then be used to determine whether a more detailed ap-

plication of geostatistical techniques would be useful in refining the existing monitoring program. Furthermore, development of semivariograms of chemical concentrations enables the underlying statistical structure of the chemical data to be evaluated. Subsequent kriging realizations can provide unbiased representations of the distribution of chemicals at different locations in the subsurface, enabling the extent of chemicals to be evaluated more accurately and effectively. Several commercially-available software packages are available to support these types of statistical evaluations; a review of these programs is beyond the scope of this appendix.

G.3 REFERENCES

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